Journal of
Experimental Psychology

VOL. 20, NO. 4 APRIL, 1937

THE PITCH OF TONES IN MELODIES AS COMPARED WITH SINGLE TONES

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Two previous studies attempted to demonstrate certain phenomenal changes in the pitch of tones in melodies, changes which are presumably due to the presence of other tones in the total configuration which constitutes the melody. In both studies the tones compared were imbedded in repeated melodies. In the first case [1] the material used was the Seashore Test of Musical Memory, in which a short melody composed of from two to six tones is repeated with one tone altered to the extent of one semitone. The typical result was that the other tones, presumably identical in frequency in both playings of the melody, tended to shift in the same direction as the altered tone. In the second study [2] the same melodies were repeated *without* any altered tone in the second playing. This constituted one form of control experiment for the first study. The systematic phenomenal changes that were found correlating with the physical alterations in the first study did not appear in the second. This confirms the conclusion that those phenomenal changes found in the

[1] J. P. Guilford and R. A. Hilton, Some configurational properties of short musical melodies, THIS JOURNAL, 1933, 16, 32–54.

[2] J. P. Guilford and H. M. Nelson, Changes in pitch of tones when melodies are repeated, THIS JOURNAL, 1936, 19, 193–202.

first study were in a large measure a function of the altered tone.

The second study showed, however, that there are many significant phenomenal changes even when a melody is merely repeated. The dynamic interplay of tones that are juxtaposed in time and unified in the temporal form which obtains in a melody is truly a very complicated affair. The mere proximity of a second tone to a first may have its measurable effect. A tone in isolation is one thing; in the presence of another tone it is something else. The problem reduces itself to a somewhat simpler form if viewed in this way. It was our purpose in this study to obtain comparisons of isolated tones with identical tones, or with similar tones, heard within a melody. By 'identical tones' we can of course only mean tones produced under physical conditions that are as nearly identical as we can practically make them. In using the expression 'isolated' tones we realize that the complete isolation of a tone is impossible, especially when it comes in temporal sequence with other tones and when *O* is set to compare it with another tone. Only a relative isolation can be assumed under the conditions of this study.

The Material

We begin the investigation with the simplest possible case; that of the two-tone melody. For the sake of comparing the results with previously obtained data, we employed the two-tone melodies of the Seashore test to which we have already referred. For a systematic set of experiments better material could obviously be selected. Many conditions should be systematically varied; the direction of the melody, whether ascending or descending; the steepness of the gradient; the position of the tones in the musical scale; the musical properties of the melody; the temporal relations of the isolated tone with respect to the melody; and various combinations of these factors. The list of ten two-tone melodies of the Seashore test present limited variations of an unsystematic sort. In the preparation of a new phonographic record, however, we were able to introduce some of the required variations.

The phonographic record was prepared in the University of Iowa Psychological Laboratory.[3] The tones and melodies were played by an accomplished flutist who attempted to attain true pitch, constant intensity and timbre. In half the series the isolated tone follows the melody and in the remaining half it precedes the melody. In some of the series the isolated tone is identical in pitch with one of the two tones in the melody and in others it differs by one semitone, just as it does in the Seashore test record. The tones and melodies were played as in 4/4 time, at the rate of 94 per minute, with a quarter rest between the single tone and the melody. The entire list of melodies with their comparison tones is given in Table 1.

TABLE 1

LISTS OF THE MELODIES AND SINGLE TONES MAKING UP THE EIGHT EXPERIMENTAL SERIES *

	I		II		III		IV		V		VI		VII		VIII	
1	c♯g	c♯	c♯g	g♯	c♯g	d	c♯g	g♯	c♯	c♯g	g	c♯g	d	c♯g	g	c♯g
2	f a	f	f a	a	f a	e	f a	a	f	f a	a	f a	e	f a	a	f a
3	a♯g	a♯	a♯g	g	a♯g	b	a♯g	g	a♯	a♯g	g	a♯g	b	a♯g	g	a♯g
4	c d♯	c	c d♯	d♯	c d♯	c	c d♯	d	c	c d♯	d♯	c d♯	c	c d♯	d	c d♯
5	b f	b	b f	f	b f	b	b f	f♯	b	b f	f	b f	b	b f	f♯	b f
6	e g	e	e g	g	e g	d♯	e g	g	e	e g	g	e g	d♯	e g	g	e g
7	c g♯	c	c g♯	g♯	c g♯	c	c g♯	a	c	c g♯	g♯	c g♯	c	c g♯	a	c g♯
8	d♯ f♯	d♯	d♯ f♯	f♯	d♯ f♯	d♯	d♯ f♯	g	d♯	d♯ f♯	f♯	d♯ f♯	d♯	d♯ f♯	g	d♯ f♯
9	a♯d♯	a♯	a♯d♯	d♯	a♯d♯	b	a♯d♯	d♯	a♯	a♯d♯	d♯	a♯d♯	b	a♯d♯	d♯	a♯d♯
10	f♯d	f♯	f♯d	d	f♯d	g	f♯d	d	f♯	f♯d	d	f♯d	g	f♯d	d	f♯d

* The letters all refer to a single octave, the second above middle C.

The contents of Table 1 show the eight series of material. In series I the melody precedes and tone 1 is repeated in isolation. Series II is the same as I except that tone 2 is repeated for comparison. In series III the melody precedes and the isolated tone is to be compared with tone 1, but wherever tone 1 is altered in the Seashore test it is altered here in the same direction, in isolation. Series IV is like series III except that the isolated tone is to be compared with tone 2 in the melody; sometimes there is a physical change of

[3] We again express our indebtedness to Dean C. E. Seashore, who placed at our disposal the equipment for making the record, and to Dr. D. A. Rothschild, who supervised the preparation of the record.

one semitone in tone 2, to agree with the original Seashore record. In the original test record tone 1 was altered in melodies 1, 2, 3, 6, 9, and 10, and tone 2 was altered in melodies 4, 5, 7, and 8. Consequently, the first-mentioned melodies, 1, 2, 3, 6, 9, and 10, have an altered isolated comparison tone in series III, and the second group, melodies 4, 5, 7, and 8, have an altered comparison tone in series IV. This means that melodies 4, 5, 7, and 8 in series III, and their comparison tones, are identical with the corresponding items in series I, and that melodies 1, 2, 3, 6, 9, and 10 in series IV, and their comparison tones, coincide with the corresponding items in series II. This enables us to check the consistency of our *O*s when they make the same kind of judgments upon the same melodies and their comparison tones when heard in a different setting.

Series V to VIII inclusive are set up like series I to IV, except that the single comparison tone precedes the melody in every case. In series V and VI there are no physical alterations in the two tones to be compared. In series VII there are physical changes in tone 1 in items 1, 2, 3, 6, 9, and 10; and in series VIII there are physical changes in items 4, 5, 7, and 8. The remaining items in series VII and VIII are duplicates of the corresponding items in series V and VI, since no physical alterations were introduced in them. In the experimental arrangements represented in Table 1 we have the material from which several questions can be answered.

Some Specific Problems

In the previous investigations with melodies one of the most troublesome methodological problems was the fact that the two tones being compared were separated by intervening time and also by intervening tones. The intervening tones represent in part the very phenomenon we are attempting to investigate—the dynamic influences of neighboring tones. But they may also represent in part merely a general interference effect such as one could get from nontonal stimuli. In the simple case that we have selected for this study, we can eliminate entirely all intervening tones, as in series II,

IV, V, and VII. Comparing the results from these series with those from series I, III, VI, and VIII, we can estimate the effect of one intervening tone.

From the nature of the material, then, we have the problem of comparing cases with and without an intervening tone. We have the problem of comparing cases when the melody precedes and when it follows the single tone. We have the general problem of determining the relation of the constant error, if any is found, with the relative pitch of the third tone. Is the constant error correlated at all with the slope of the melody, whether ascending or descending, and/or with the steepness of the slope? How do the phenomenal changes with this type of comparison agree with those found by Guilford and Nelson when the entire two-tone melody is repeated? The latter case involves the presence of the third tone two times in the observational situation. Is its effect thereby intensified? Fortunately, the same *O*s were used in both studies and so their phenomenal changes should be directly comparable. We should like to make the same kind of comparison for the altered tones. Is the change of one semitone any more noticeable when the comparison tone is isolated from a melody than when it is in the same melody as the other comparison tone? We cannot answer this question, for the comparison will have to be made with some corresponding data obtained by Hilton [4] in which another set of *O*s was employed. We shall present the comparison, however, because of the interest that should attach to this variation of the general problem, and because certain facts are thereby made clear in spite of the use of different *O*s.

Experimental Procedure

Observers.—The *O*s were the same ten individuals who served in the preceding study.[5] Half of them had had varying degrees of musical training. Their *DL*'s for pitch, as determined by the use of Seashore's Sense of Pitch Test, ranged from 1.37 to 6.83 dv., with a mean of 3.10 dv.

[4] R. A. Hilton, Some configurational properties of short musical melodies, a master's thesis on file in the University of Nebraska Library, 1931.

[5] Guilford and Nelson, *op. cit.*

Observations.—The ten *O*s were instructed to give judgments always in terms of the second comparison tone, whether it was higher, lower, or equal to the first. Judgments of 'doubtful' were given when *O* was certain of a change but uncertain of its direction and judgments of 'questionable' when *O* failed to make the comparison at all. Every pair of tones was judged 200 times, making a total of 16,000 responses which serve as the data for this study.

Results

Treatment of the Results.—The phenomenal changes in the comparison tones were computed as in the previous studies. The judgments of all ten *O*s were combined for every melody. Of the judgments 'higher' and 'lower' we calculated for every comparison the proportion that were 'higher.' Adopting again the principle that "Equally often noticed differences are equal unless always or never noticed," we transformed every proportion into a corresponding deviation in terms of *PE* as the unit. Assuming that the observations are independent, the reliability of any proportion may be given in terms of its standard error.

More properly, we may determine the standard error for a proportion of .50, which assumes a purely chance division of the judgments 'higher' and 'lower,' and then see whether our obtained proportions differ sufficiently from .50 to justify our assurance that they did not occur from random sampling. When p (the proportion) equals .50, $\sigma_p = .5/\sqrt{N}$. In our data, N varies from one comparison to another, since more than two categories of judgment were permitted. The total number of 'higher' and 'lower' judgments ranged between 77 and 196, with most of them between 100 and 150. With N equal to 77, $\sigma_p = .057$. A deviation in p from .500 of .057 is equivalent to a deviation of .213 *PE* units. Thus, for any phenomenal shift of plus or minus .213 units, the chances are 2 : 1 that the change is not due to sampling errors. When the obtained proportion deviates $2\sigma_p$, or .114 from .500, the corresponding phenomenal shift is .430. The chances are about 1 : 42 that a shift as large as this could occur in either

direction as a result of sampling errors alone. When the shift is .539 *PE* units, the probability of such a change by pure chance is about 1 : 160. When N is 150, which may be regarded as more typical, $\sigma_p = .041$. In this case a phenomenal shift as large as .303 may be taken as being significant (the chances are 42 : 1 that the shift could not have been obtained from a random selection in a pure chance situation) and a shift as large as .383 may be regarded as highly significant (the chances of a shift that large coming from sampling errors being 1 : 160). In Table 2 it is seen that 19 of the 80 changes fail to meet the test of high significance, but only 8 would be regarded as insignificant by the same test if N is 150. We should be willing to accept any change greater than .400 as significant and any change greater than .500 as being highly significant. Very satisfying evidence concerning the reliability of the phenomenal changes is afforded in Table 3, where repeated evaluations of the same comparisons are given.

In Table 2 we have the complete list of changes in terms of *PE* units. A negative sign means that the second comparison tone was judged lower than its mate and a positive sign means that it was judged higher. *O* always judged in terms of the second of the two tones, as is customary in psychophysical experiments. In the last four series the second tone was always in the melody. What effect the set to judge in terms of the second tone may have had we cannot say. Certainly, the relative deviation of the *single* tone from this tone in the melody was almost universally reversed in direction for the cases when it was first as compared with the cases when it was second (see Table 2). But there are other, more apparent differences between series I to IV and series V to VIII, so we cannot say that *O*'s set toward comparison tone 2 is responsible for the universal difference just pointed out.

If we wish to estimate what happens to the isolated tone in series V to VIII, we may assume that if the tone in the melody is judged lower the isolated tone must have been higher, and vice versa. Actually, we cannot tell whether the

TABLE 2

PHENOMENAL CHANGES IN THE SECOND COMPARISON TONE *

Melody	I	II	III	IV	V	VI	VII	VIII
1	−2.178	+ .434	+ *.536*	+ .112	− .445	+ .350	−*1.649*	− .403†
2	+1.436†	+ .422	−*1.080*	+ .641	+ .329†	+ .730	+*1.389*	+ .945
3	+1.892	−1.961	+*3.634*	−2.095	+ .368	− .468	−*1.517*	− .314
4	−1.926	− .905†	−1.699	− *.349*	− .376	− .449†	− .303	− *.171*
5	+1.395	− .991	+1.498	−*1.372*	+1.536	− .078	+1.485	− *.216*
6	− .834	+ .559	−*2.494*	+ .749	± .000	+ .243	+*1.636*	+ .277
7	−1.180	+1.670	−1.339	+ *.698*	− .641	+ .945	− .620	+*1.238*
8	+ .360†	−1.418†	+1.028†	− *.604*	− .408	−1.080†	+ .624†	− *.715*
9	+1.810	−1.384	+*3.634*	−1.601	+1.780	− .536	−*1.867*	− .357
10	− .604	−1.065	+*2.016*	−1.204	− .108†	− .131	−*1.549*	− .728

* Numbers in italics refer to changes accompanying physical differences of one semitone.

† These numbers refer to cases which deviate from the general law of contrast.

single tone has made an absolute shift upward or whether the tone in the melody has made a shift downward, or whether both of these changes have occurred. We are forced to assume only relative changes in any case. Even so, the relative shifts of the isolated tones tend to lie in opposite directions, when they come before the melody as compared with when they come after it. There is more agreement between the behavior of the second of the two comparison tones, one isolated and the other in the melody, than there is between isolated tones or between tones-in-melodies as such.

It is difficult to see from Table 2 alone whether there is any rhyme or reason to the phenomenal changes, the majority of which we have decided cannot be due to chance. Figure 1 will be of more help in hunting for general trends. Here the melodies and their comparison tones have been displayed graphically. The drawings have been made to a scale both for the musical changes and for the phenomenal changes. It was determined empirically that an actual change of a semitone corresponds roughly to 1.200 *PE* units, under the conditions of this study, and so all phenomenal changes are plotted on that basis. The arrows indicate the direction of the shift and also its relative extent. The two tones that are compared are connected with a dotted line, and when there was an actual change of a semitone that fact is apparent in

the sloping of that dotted line. The arrow denoting the phenomenal change starts at the level of the first comparison tone, whether there was a physical change or not. Among

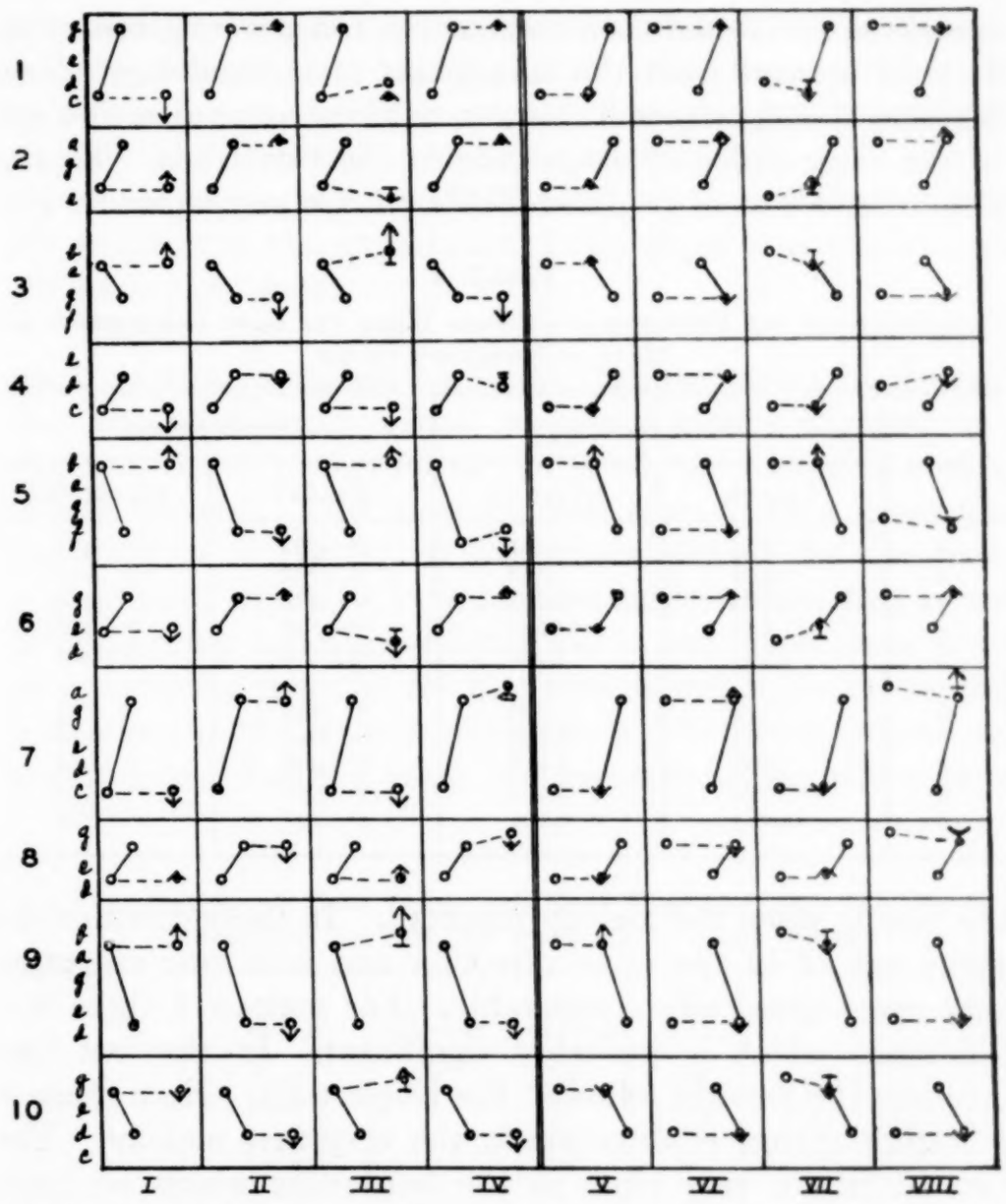

FIG. 1. Graphic representation of the 80 melodic situations presented to the observers, indicating the musical relationships among the tones and the direction and approximate amount of phenomenal changes occurring in the comparison tones.

the last four series, when the single tone precedes the melody, we have shown the phenomenal shift as if occurring in the second tone, to agree with the data in Table 2. The letters at the left of the chart are the musical notations which may

serve as a rough guide as to the position of the melody on the musical scale. A more exact determination of the position may be had by reference to Table 1.

Consistency of the Changes.—As has been mentioned before, certain melodies and their comparison tones were given twice. It is of interest from the standpoint of methodology to see whether the phenomenal shifts were in the same direction and of the same order of magnitude in the two trials. To test this point we have prepared Table 3. Columns 1 and 2 give

TABLE 3

CONSISTENCY OF THE PHENOMENAL CHANGES WHEN THE SAME COMPARISONS ARE MADE IN DIFFERENT SERIES

Series	Melody Precedes		Melody Follows	
	I and II	III and IV	V and VI	VII and VIII
1	.434	.112	+ .350	− .403
2	.422	.641	+ .730	+ .945
3	−1.961	−2.095	− .468	− .314
4	−1.926	−1.699	− .376	− .303
5	1.395	1.498	+1.536	+1.485
6	.559	.749	+ .243	+ .277
7	−1.180	−1.339	− .641	− .620
8	.360	1.028	− .408	+ .624
9	−1.384	−1.601	− .536	− .357
10	−1.065	−1.204	− .131	− .728

the results when the melody precedes. In these columns the shifts are all in the same direction and with one exception they are numerically comparable. For melody 8 there is a difference which is probably significant. In the last two columns the melody followed the single tone. Here there is a glaring change in direction in the very first melody. The two shifts are very close to the borderline which we have adopted for significant measurements of shifts in this study, however, so we cannot be greatly concerned about them. Since the tones were played on the flute, there may have been some actual physical alterations of frequency, sufficient in rare cases to cause a discrepancy such as we find in Table 3. Melody 1 also shows some discrepancy in the first two columns, but one of the measurements there is decidedly

lacking in significance and the other is on the borderline, so we cannot blame the inconsistency upon faulty observation or faulty method of treatment of results. Melody 8 shows the largest discrepancies in both columns. We find that this particular melody is a nonconformer in most respects as we shall see later, so we doubt whether these discrepancies can be attributed to the flute player, unless he makes errors in playing that particular melody on all occasions.

On the whole, the data in Table 3 are heartening, both for the validity of the experimental technique and the method of treating the data.

Contrast Effects upon Neighboring Tones.—The major result of this investigation is the demonstration of the fact that the second comparison tone is typically changed in a direction opposite to that of the third, noncomparison tone, in the melody. This may be seen even from a superficial examination of Fig. 1. It happens under all the variations of conditions which we have in this study; in ascending as well as descending melodies; when there is and when there is not an intervening tone; for the first tone as well as for the second; and whether the melody precedes or whether it follows the single tone. Table 4 gives the averages of the shifts under

TABLE 4

THE AVERAGE SHIFT OF PITCH OF THE SAME TONE WHEN REPEATED, IN A DIRECTION OPPOSITE TO THAT OF THE OTHER TONE IN THE MELODY

Case	Order: Melody	Position in Melody	Intervening Tone	Mean Shift	σ_M	M/σ_M	N
1	First	1	Yes	.886	.328	2.70	14
2	First	2	No	.825	.254	3.25	16
3	Second	1	No	.486	.177	2.77	14
4	Second	2	Yes	.200	.157	1.27	16
1 and 4	Both	Both	Yes	.520	.185	2.80	30
2 and 3	Both	Both	No	.667	.150	4.45	30
1 and 2	First	Both	Both	.853	.193	4.31	30
3 and 4	Second	Both	Both	.333	.119	2.80	30
1 and 3	Both	1	Both	.686	.175	3.92	28
2 and 4	Both	2	Both	.512	.152	3.37	32
All	Both	Both	Both	.592	.108	5.48	60

all these variations. Figure 2 shows the typical changes graphically under eight conditions.

Granting all the assumptions that we have made concerning the observations and the statistics involved, it can be seen from Table 4 that with possibly one exception (case 4, when the melody is second, when tone 2 is judged and there is consequently an intervening tone) the shifts are statistically significant. The shifts are decidedly greater when the melody precedes than when it follows. They tend to be greater for tone 1 than for tone 2. They are slightly greater when there is no intervening tone, that is, when the third tone comes

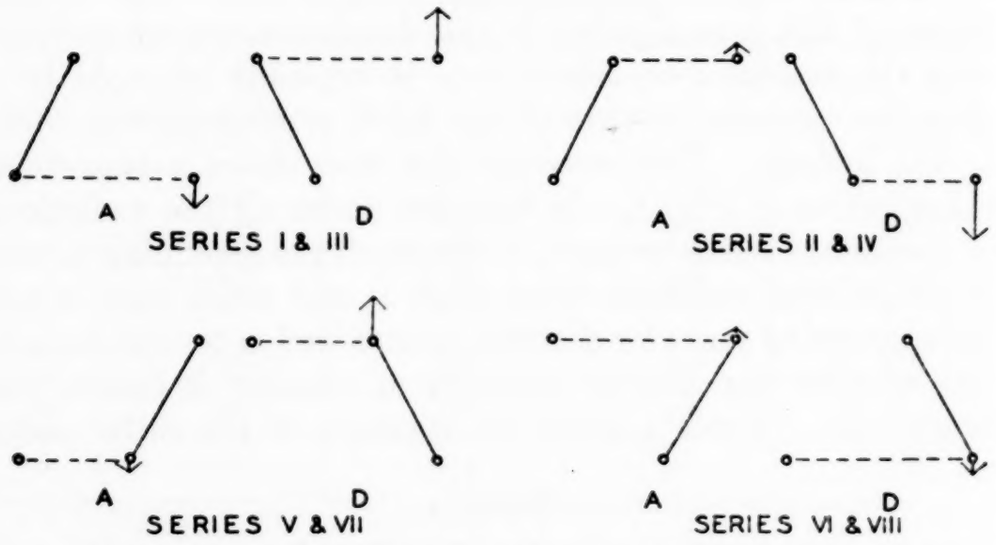

FIG. 2. Graphic representation of the 8 types of melodies, ascending (*A*) and descending (*D*), with melody preceding and following the single tone, and the typical phenomenal shift in pitch for each type.

either before or after the comparison pair. The two differences last mentioned are probably not statistically significant, but they suggest a need for a more extended and systematic study. Taking all conditions together, the mean change in the direction of contrast is .592, which is 5.48 times its standard error.

If one does not wish to depend too much upon the degree of change which we have just indicated, nor to follow us in making the assumption that justifies the use of *PE* units for measuring the changes, one may have recourse to the original proportions of judgments which indicate the direction of

change, whether in the direction of contrast or in the direction of assimilation. By assimilation we mean that the second comparison tone is judged in the direction of the third tone in the comparison situation. This type of comparison considers direction and disregards the amount of change. Table 5

TABLE 5

PROPORTIONS OF THE CASES IN WHICH THE EFFECT UPON THE SECOND TONE IN THE COMPARISON PAIR IS A CONTRAST EFFECT WHETHER THAT TONE IS IN THE MELODY OR NOT

Case	Order: Melody	Tone	Intervening Tone	Proportion		N
				p_C	CR_σ	
1	First	1	Yes	.714	1.60	14
2	First	2	No	.873	3.00	16
3	Second	1	No	.714	1.60	14
4	Second	2	Yes	.813	2.50	16
All	Both	Both	Both	.783	4.32	60

gives a brief summary of the proportions of the experimental cases that exhibit the contrast effect. The proportions range from .714 to .873 when certain types of data are kept separate, and when all data are combined the proportion of cases showing contrast effects to some degree is .783, which is 4.32 times its standard error, assuming that the cases represent independent observations. Here the proportions showing contrast are greater for tone 2 in the melody than for tone 1, in disagreement with the conclusion from Table 4, when the *amount* of change is also considered. There is slightly more significance for changes when the melody precedes than when it follows, in agreement with a very significant difference revealed in Table 4 when amount of change is considered.

It is of interest to know how much individual variability there is among the different *O*s on this question of contrast versus assimilation. Heretofore we have combined the data from all *O*s. How many single *O*s will agree that most cases fall in the category of contrast? Unfortunately, each *O* made only 20 judgments of each comparison pair. Of the 20 judgments there are many in neither of the categories 'higher' or 'lower.' When shall we say that his judgments

indicate a contrast effect and when an assimilation effect and when do they indicate neither? We adopted the following scheme for deciding this question for every single comparison pair. Whenever 19 or 20 judgments fell into the categories 'higher' and 'lower' combined, unless the judgments were 2 : 1 in favor of one or the other, we relegated it to the class of 'neither.' When the number in both categories was 16 to 18, it took a 3 : 1 ratio to be regarded as a case of either contrast or assimilation. When N was 13–15, the ratio had to be 4 : 1. When N was 9 to 12, the ratio had to be 5 : 1. A few scattered ratios of 8 : 0 and 7 : 0 were also included among the significant cases. These criteria were made on the basis of the standard error of a proportion of .50 when N varies from 9 to 20. Our cases chosen as significant for indicating contrast or assimilation have a probability of about 20 to 1 of not having arisen from a purely random situation.

Table 6 gives the number of cases out of 60 for every O that we have taken to indicate contrast and assimilation. The numbers of significant indicators vary from one O to

TABLE 6

PROPORTIONS OF EVERY OBSERVER'S JUDGMENTS THAT EXHIBIT THE CONTRAST EFFECT IN SIXTY EXPERIMENTAL CASES

O	Numbers of Cases Showing Contrast or Assimilation or Neither						Proportion Showing Contrast	Critical Ratio CR_σ
	Melody Precedes		Melody Follows		Both			
	C	A	C	A	C	A		
A	10	3	1	0	11	3	.785	2.02
C	8	14	3	12	11	26	.336	−2.00
D	15	6	12	4	27	10	.730	2.77
F	25	5	19	4	44	9	.830	3.33
G	3	7	1	1	4	8	.333	−1.16
HB	17	5	13	4	30	9	.771	3.39
HC	23	4	10	6	33	10	.767	3.51
HE	0	0	0	0	0	0	—	—
N	13	9	8	5	21	14	.600	1.19
S	15	2	7	1	22	3	.880	3.80
Totals	129	55	74	37	203	92	.688	6.47
Proportions	.701		.666					
CR_σ	5.43		3.50					

another. One *O* had none at all while another *O* had 80 percent that are significant according to our criteria. The median number of significant indicators for the ten *O*s is 36, or 60 percent. Since *N* varies, so will the standard error of the proportion of cases that show contrast for each *O*. The critical ratios are given in the final column of Table 6. It should be added that here, as well as in Table 5, we have computed the standard error of a proportion of .50 rather than of the obtained proportion. From this and the deviation of the obtained proportion from .500, we can determine the probability that such a proportion could have arisen if there were no basis for it except pure chance.

From the last two columns of Table 6 it will be seen that 5 *O*s are practically certain to get a contrast effect more frequently than an assimilation effect, the critical ratios being greater than 2.50. Two more have critical ratios greater than 2.00. One *O*'s status is entirely indeterminate, since she gave no significant indicators of either contrast or assimilation. Two *O*s had a greater proportion of indicators for assimilation than for contrast, but only one of these had a critical ratio as large as 2.00. Just why two *O*s out of 10 seem contrary to the others we cannot say. One of these, *C*, had had considerable musical training and had been a teacher of music. But observer *N* had probably had an equivalent amount of musical training and experience, and her judgments are on the side of contrast, though not quite so assuredly as those of *C* are on the side of assimilation. At least two others who are decidedly on the side of contrast have also had some musical training. A difference in musical training cannot therefore account for the difference in predilection for assimilation as opposed to contrast for the *O*s represented in Table 6.

While we believe that our general law of contrast is well established, we cannot ignore certain notable exceptions to the rule. Exceptions, in our opinion, do not upset the law. They merely indicate the fact that there are other causal factors operating that we have not controlled. Other laws are coöperating to produce the phenomenal changes, and in

some cases these factors are opposed to a net contrast effect. Among the disturbing factors may be faulty preparation of the tones. We have had no opportunity to check up on the physical frequencies that were used. In view of the fact that the contrast effect, and perhaps unknown factors as well, can produce a change in pitch that is opposite in direction to that which results from the physical change of a semitone, we are inclined to discount the force of any small physical deviations in frequency that may occur in the playing of the tones.

Of all the melodies showing exceptions to the law of contrast, number 8 is the chief offender, with five exceptions out of six comparisons, when there is no physically altered tone. Other offenders are melodies 2 and 4, with two exceptions each. The only striking similarities in these three melodies are that they are all ascending in slope and that the gradient is rather low as compared with that in other melodies. What may make matters worse, melody 8 is sandwiched between two melodies with decidedly steep gradients. These considerations suggest that the contrast effects may be related to the steepness of the melody, or to the degree of difference between the two tones in it. Melodies 3 and 10 are the only descending ones with relatively small slope, but of these, only melody 10 has an exception to the rule of contrast, and that exception is certainly insignificant. To test the matter further, however, we computed a linear coefficient of correlation between (1) the amount of shift in the direction of contrast and (2) the number of semitones difference between the two tones of the melody. The Pearson r is $+0.378$, which is nearly three times its standard error and is therefore highly significant.

There are no other reasons obvious to the writers why melody 8 in particular is guilty of most of the glaring exceptions. Exceptions like this are interesting, because they show one where to seek for any factors that help to violate a general rule and they may lead to a modification of the general law or to the formulation of a more comprehensive law that will include the exceptions. With the limited and unsystematic variations with which we must work here, we

cannot go far in the direction of this goal. We need other consistent exceptions like those with melody 8 in order to follow up the clues afforded by it. We need experimental variations of melody 8 and others like it in order to see under what conditions contrast might occur and when it will not.

Contrast Effects in Ascending and Descending Melodies.— There is no particular reason why with our simple experimental material that there should be any systematic difference between ascending and descending melodies in their proneness to show the contrast effect. As it turned out, the descending melodies show a decidedly greater tendency to contrast effects than do ascending tones, either when the melody precedes the tone or when it follows. Table 7 shows this comparison.

TABLE 7

CONTRAST EFFECTS IN ASCENDING AS COMPARED WITH DESCENDING MELODIES, FOR TONE 1 AS COMPARED WITH TONE 2, AND FOR THE TWO TIME ORDERS, MELODY FIRST AND SECOND

	Ascending Melodies				Descending Melodies			
Order	Melody First		Melody Second		Melody First		Melody Second	
Tone	1	2	1	2	1	2	1	2
Mean.....	.704	.252	.204	.173	1.198	1.472	1.012	.373
Both Tones....	.478		.189		1.358		.639	
Both Orders....	.334				.998			
σ_M.....	.148				.181			
CR_σ.....	2.26				5.51			

We shall have to remember, again, that the melodies of the Seashore test are not prepared so that the two sets of ascending and descending melodies are equivalent or comparable in other respects than their direction or slope. We can only hope that other aspects not systematically held constant will vary at random so that any difference found between the two sets is not rather to be attributed to some other systematic variation which perchance is the real secret of the obtained difference.

In Table 7 the row of means gives the average contrast effect for the eight cases represented in Fig. 2. Since these are based upon only 5 to 9 different measurements each, we cannot place too much credence in them, but they are suggestive. The arrows that indicate the typical shift in Fig. 2 are drawn proportional in length to these means. We make no attempt to explain any of the differences that are suggested by Table 7, lest we be performing the gratuitous task of trying to explain something that is not so. The two final means, based upon 36 and 24 cases respectively, are decidedly different, and the difference is probably significant. It remains to be seen whether descending melodies, which differ from ascending melodies only in the respect of their slope, will generally be found to give a greater contrast effect.

Contrast Effects in the Altered Tones.—We believe that it can be demonstrated from the data in Table 2 that the general contrast effect which we find for identical comparison tones can also be found under similar conditions when there is a difference of one semitone between the comparison tones. If the physical shift is in the same direction as that called for by the contrast effect, we might expect a summation of those two factors and an enlarged total shift in pitch. This seems to be apparent in series III, melodies 3, 9, and 10, for example. But when the physical change is in a direction opposed to that of the contrast effect, then we might expect a mutual cancellation and a slight total change as a result. If the contrast factor is strong enough it might even overcome the physical factor as in series VIII, melody 7, for example. Cases of partial cancellation of the two opposing factors may possibly be those in series III, melody 1, and in series IV, melody 4. There are cases in which both factors should be allied but the result is surprisingly small, as in series III, melody 2, series IV, melody 7, and series VIII, melody 5. Wherever known physical change and contrast effects do not lead to the expected combined result, then we must look for other causal factors. We believe that a careful examination of Fig. 1 will show that wherever contrast effects are not fulfilled in the altered tone, they are likewise inclined to fail

to appear in the corresponding melodies when there is no physical change.

In Table 8 are given the data from which we may make the comparison which we want in this phase of the problem. In the first column are given the phenomenal changes when the physical alteration was in the same direction as that which is needed to satisfy the law of contrast. In the second column are given the phenomenal shifts when the physical changes were in a direction opposed to that of the contrast effect. In every case the algebraic sign is given in terms of agreement or lack of agreement with the physical alteration. A plus

TABLE 8

CONTRAST EFFECTS SUPERIMPOSED UPON THE EFFECTS OF PHYSICAL ALTERATIONS IN THE COMPARISON TONES

Melody	Physical Change Plus Contrast Effect	Physical Change Minus Contrast Effect
1	1.649	.536
2	1.080	1.389
3	3.634	1.517
4	− .171	.349
5	.216	−1.372
6	2.494	1.636
7	.698	−1.238
8	− .604	.715
9	3.634	1.867
10	2.016	1.549
Mean	1.465	.695

sign means that the direction of the phenomenal shift is the same as that of the physical change. The signs might all be expected to be positive, but the facts are otherwise. Four of them are negative, three of them significantly so. In column 2 this may be more understandable; the contrast effect, when opposed to it, might at times overcome the effect of the physical change. But the two exceptions in column 1 have occurred in directions opposed to *both* factors combined. The significant one is attached to our old offender, melody 8 again. The other lacks statistical significance, but even a lack of positive change should call our attention to itself here. No explanation for these two surprising exceptions is apparent.

In order to determine the extent of the contrast effect in the altered comparison tones, we have computed averages of the ten cases in which physical change and contrast effect should give mutual reinforcement and also the ten cases in which the two factors are opposed in direction. In the former, the mean shift is 1.465 *PE* units and in the latter the mean is .695. The difference between the two is .770 units in favor of the cases in which the two factors coöperate. This value compares very favorably with the grand average shift in the direction of contrast given in Table 4, namely, .592 units. However, if we assume that the factor of contrast in the comparison made above works just as strongly *against* a change as it does *for* a change, then only half of .770, or in other words, .385 units, is the average strength of the contrast factor when there is a physical change of a semitone. This difference is not statistically significant, but we believe that with systematically controlled observations and a larger number of cases the difference would be verified. At any rate, the problem of finding the contrast effect is amenable to experimental attack. Variations of the physical alterations through differences smaller than semitones might be fully expected to ascertain the point at which the two factors are perfectly balanced for any given melody.

Contrast Effects When the Whole Melody is Repeated.—To what extent does the contrast effect operate when the whole two-tone melody is repeated without physical change? From an examination of series I, in Fig. 1, we see that if the whole melody were repeated the second comparison tone would then be entirely surrounded by the additional tone of the melody. The additional tone would then come both before and after the second comparison tone. One might not expect a tone following the second comparison tone to have any influence upon it, but such an effect has occurred in other places. For example, we get a measurable effect, though rather small, in series V, in which the extra tone merely comes after the second comparison tone. We might predict, then, that when the whole melody is repeated there will be an intensified contrast effect upon tone 1 in the melody.

If we direct our attention to series V, in Fig. 1, we can see that the repetition of the melody would place the extra tone between the two comparison tones where nothing intervened before. The contrast effect should again be intensified. The effect upon series II should be a similar one; the extra tone is interpolated between the two comparison tones when the whole melody is repeated. What would happen to series VI is another thing. The extra tone is then given preceding the first comparison tone. The *first* comparison tone is then surrounded on either side by the extra tone. The contrast effect might be expected to accrue to the first tone and an assimilation effect might therefore appear in the second tone and its relation to the first. This argument would lead us to expect more assimilation effects when tone 2 is judged than when tone 1 is judged. This is apparently the case, as we shall see from Table 9 and in the discussion to follow. The material of Table 9 was supplied from a previous study in which the entire melody was repeated.[6] The data are compared with corresponding data obtained in Table 2. The same *O*s were used in the two cases, so the values are numerically comparable.

In column 1, when tone 1 is judged, there are 7 cases of contrast as compared with 3 cases of assimilation. How many of these measurements are significant of a real change we are not sure. Adopting any shift greater than .400 as being significant, as we have done before, four of the measurements fail to meet the test. Three of these are the cases of assimilation and the fourth is a case of contrast. The 70 percent (7 out of 10) of cases of contrast, although unreliable, is very close to the proportion of contrasting cases when a single tone is repeated from the melody (see Table 5). We may conclude, therefore, that so far as the first tone of the melody is concerned the factor of contrast seems to be operating just as extensively as when only one tone is repeated. The average contrast effect, based upon all ten measurements, is only .297 units, however, as compared with an average change of .886 to be found for the corresponding cases in Table 4. Clearly,

[6] Guilford and Nelson, *op. cit.*

the contrast effect is not intensified by the addition of the extra tone. This may be a case of failure or inability to predict the whole from the part. There may be something about the completeness of the repeated melody that is lacking in the single comparison tone. The two comparison tones may become better stabilized in the process. We should be reluctant to fall back upon this rather vague type of explanation, however, preferring to keep faith in an ultimate analysis of the dynamic relationships between neighboring tones whether they are parts of wholes or whether they are not.

The results for tone 2 show a somewhat different situation. In the second column of values in Table 9 there are 3 examples

TABLE 9

PHENOMENAL CHANGES IN PITCH WHEN THE TWO COMPARISON TONES ARE BOTH IN THE MELODY AND WHEN ONE IS PRESENTED OUTSIDE THE MELODY

Melody		Both in the Melody		One in the Melody and One Alone			
				Melody First		Melody Second	
No.	Slope	Tone 1	Tone 2	Tone 1	Tone 2	Tone 1	Tone 2
1	a	− .628	− .179	−2.178	*.273**	− .445	− *.027*
2	a	.424	1.041	1.436	*.532*	.329	*.838*
3	d	.303	.037	1.892	*−2.028*	.368	− *.391*
4	a	− .575	− .228	*−1.813*	− .905	− *.341*	− .449
5	d	1.099	.528	*1.447*	− .991	*1.511*	− .078
6	a	.197	− .243	− .834	*.654*	.000	.260
7	a	− .548	1.388	*−1.260*	1.670	− *.631*	.945
8	a	.190	− .559	*.694*	−1.418	*.108*	−1.080
9	d	.950	− .209	1.810	*−1.493*	1.780	− *.447*
10	d	− .326	.056	− .604	*−1.135*	− .108	− *.430*
Mean contrast effect		.297	.081	.886	.825	.486	.200

* Values in italics are the means of two independent measurements.

of contrast effect and 7 of the assimilation effect. Six of the measurements fail to meet the test of significance, 5 of them being cases of assimilation and 1 a case of contrast. This leaves 2 significant examples of each type. The mean shift, based upon all ten measurements, is .081 units in the direction of a net contrast effect. Combining the two sets of measurements, the grand average is .189 units of change in the direction of contrast.

It seems apparent that the contrast effect is smaller when the whole melody is repeated than when only one tone is repeated, and that this is more true when tone 2 is the comparison tone. The last fact was predicted from the arguments above, but the first was not. If the repetition of the entire melody does stabilize all the tones concerned, it may have a greater influence upon tone 2 than upon tone 1. The stabilization may be greater when *O*'s attention is directed to tone 2 than when directed to tone 1. Suppose that his attention is upon tone 1 when the whole melody is repeated. He is set to make a judgment the moment tone 1 occurs in the second melody. He can more or less ignore the last tone to come. His set superimposes itself upon the other factors already present. Whether or not *O*'s set acts in just the manner we have indicated is not so important. The fact that set is an additional factor with distorting power in its own right complicates the entire judgment situation. Individual differences in set, for example, might account for the individual differences represented in Table 6. One *O* gets more cases of assimilation than of contrast because he is taking the group of three tones in a different observational manner than do the others who get a strong majority of contrast effects. This can be taken as an argument to support our practice of pooling judgments from different *O*s. In so doing, the incidental differences due to individual differences in set will cancel out to some extent.

The failure to obtain a universal contrasting change, even for tone 1 in the repeated melodies, should be expected. A contrast effect was not apparent in 22 percent of the cases even when only one tone was repeated. Let us see whether the choice between the two types of changes is consistent for comparable cases in the two investigations. The amount of agreement is indicated by the proportion of the times that the algebraic signs coincide in Table 9. Since we have a double set of data when the single tone is compared, we can make a double comparison for agreement or lack of agreement. When tone 1 is judged there are 20 pairs of observations. Of these, 19 are in agreement and 1 is not. The one exception comes from melody 6 when the single tone follows. This

agreement of 95 percent gives a much better basis for saying that shifts of the comparison tones obey the same laws when either or both are in melodies, at least so far as tone 1 is concerned. In the case of tone 2, however, there are ten agreements and ten disagreements. These disagreements are evenly divided among the cases in which the melody precedes the single tone and those in which it follows. If we include only significant measurements (shifts greater than .400) in this comparison, there are 6 agreements and 1 disagreement.

Contrast Effects When There Are Physical Alterations and the Whole Melody is Repeated.—We have already found that contrast effects make their appearance to some extent when the comparison tones are one semitone apart and one of the comparison tones is not in the melody. Will this also be true when the entire melody is repeated? Without any physical change in the comparison tones we have just seen that if the entire melody is repeated the contrast effects are still apparent in tone 1 but they are obscured or reduced to doubtful importance for tone 2. To answer the question just stated, let us resort to some data which were supplied by Hilton's[7] study. They are given in Table 10 along with the corresponding data from our own study for comparison. Owing to the limited number of cases, we should perhaps content ourselves with a comparison of single pairs of observations. If we do so, we note that there is fairly good agreement as to the sign of the shift, but not as to the amount. Melodies 3, 9, and 10 are three very similar in form, all being descending, with a change in tone 1 that is upward. Hilton's data show consistently greater shifts in pitch. Her *O*s were different from ours, but the mean *DL* was very nearly the same in both groups of *O*s. Hilton's greater changes may be attributed to the fact that the entire melody was repeated. But this would be surprising in view of the fact that in her case an extra tone is being brought into the situation and therefore might be expected to interfere with the clear observation of an objective change.

[7] Hilton, *op. cit.*

A contrast effect in Hilton's data is not apparent unless we resort to averages again in spite of the very small numbers of samples. In addition to the handicap of small samples is the fact that two of Hilton's phenomenal shifts are measured by a proportion of 1.00. With N equal to 175 we assume that the range of variation is approximately 9 PE units, which may normally be expected with 175 cases. The two shifts are therefore estimated as 4.500 units; they may actually be larger.

TABLE 10

SHIFTS IN PHYSICALLY ALTERED TONES WHEN THE COMPARISON TONES ARE IN REPEATED MELODIES AND WHEN ONE OF THEM IS ALONE*

Melody	Slope	Physical Change	Tone Changed	Both Tones in Melodies	One Tone Alone	
					Melody First	Melody Second
1	a	+	1	.587	*.536*	1.649
2	a	−	1	−3.090	*−1.080*	−1.389
3	d	+	1	4.500†	*3.634*	1.517
4	a	−	2	−2.015	− .349	*.171*‡
5	d	+	2	2.211	−1.372‡	*.216*
6	a	−	1	−3.125	*−2.494*	−1.636
7	a	+	2	.603	.698	*−1.238*‡
8	a	+	2	.539	− .604‡	*.715*
9	d	+	1	4.500†	*3.634*	1.867
10	d	+	1	2.788	*2.016*	1.549

* Numbers in italics represent cases in which a third tone intervened between the two comparison tones.

† These values are rough estimates. The proportions were 1.000 when $N = 175$.

‡ These cases represent phenomenal shifts in a direction opposite to that of the physical change.

As in the previous examination of the role of contrast when there are physical changes, we compute the average shift when contrast effect and physical change are coöperating and when they are opposed. There are 7 cases of coöperation, with a mean of 2.735, and three cases of opposition with a mean of 1.604. This is rather a strong indication of a contrast effect when the tone is altered and when the whole melody is repeated. In spite of a presumably stronger factor of a physical change of one semitone, the contrast effect is still to be reckoned with. It would seem that this applies

much more strongly when tone 1 is compared than when tone 2 is compared, to agree with the result when there was no physical change in the repeated melody, but we are certainly not in a position to make much of this point. Suffice it to say that the results of the type which we have cited from Hilton's study seem consistent in every way with the new results which we have more recently obtained, and that we have come closer to explaining the results obtained when repeating the entire melody, either with or without an altered tone.

Summary and Conclusions

In this investigation we have attempted to continue to measure phenomenal changes in the pitch of tones which may be attributed to the presence of other tones in a melody. The changes in pitch have been determined for the two-tone melodies in the Seashore Test of Musical Memory under a variety of conditions: (1) When the tone in a melody is compared with another outside the melody, either preceding or following. (2) Under the same conditions as in (1), except that a change of one semitone is introduced as in the Seashore test. (3) When the whole melody is repeated with no physical changes. (4) When the whole melody is repeated with one tone changed to the extent of one semitone. The results that can be generalized for situations like those presented in our material are:

(1) Significant phenomenal changes do occur in a tone that is repeated in the melodic situation, whether only one of the comparison tones or both are a part of a melody.

(2) These phenomenal shifts are rather consistent as to direction and as to extent when the same melodic situation is duplicated at different times or in different sequences or with different sets of observers.

(3) When a single tone of the melody is repeated, the shift from the first comparison tone to the second is most likely to be in a direction opposite to the position of the other tone in the melody. This may be called a contrast effect. There are significant exceptions to this general rule, however, and so other causal factors must be sought to account in full for the phenomenal shift in any particular case.

(4) The contrast effect is slightly stronger, (1) when there is no intervening tone between the two comparison tones, (2) for tone 1 in the melody than for tone 2; it is decidedly stronger (3) when the melody precedes the single comparison tone, and (4) when the melody is descending rather than ascending in slope.

(5) Two of the 10 *O*s showed a slight majority of cases which were contrary to the rule of contrast, 7 showed fairly reliable majorities in the direction of contrast and one *O* had no significant shifts at all.

(6) There is a significant though low positive correlation between the steepness of the melody and the extent of the contrast effect. Cases of assimilation (the reversal of contrast) were most common among melodies with a low gradient, and these were usually of the ascending type.

(7) Tones that are altered by one semitone also show the contrast effect superimposed upon the shift corresponding to the physical change. This is true either when only one tone is given outside the melody or when both are in repeated melodies.

(8) When the entire melody is repeated, either with or without a physical change in the comparison tone, tone 1 of the melody is much more subject to the contrast effect than is tone 2.

(9) Wherever contrast effects fail to appear with a single tone repeated they are also almost sure to be missing when the whole melody is repeated.

(10) It remains only for a patient, systematic variation of conditions, with ascending and descending melodies, with physical changes of a semitone or less in both directions, with the slope altered in varying numbers of semitones, with melodies of two, three, or even more tones, and with other systematic variations of the same melodies, to determine the necessary and sufficient conditions for contrast and assimilation effects and to uncover other as yet unknown factors that produce phenomenal changes in tones that are under the influence of neighboring tones in melodies.

(Manuscript received August 17, 1936)

THE RESPONSE OF THE COCHLEA TO TONES OF LOW FREQUENCY

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The action of low tones upon the ear presents a number of problems. One of these is the problem of the lower limit of pitch. In human hearing it is generally agreed that at 20~ or thereabouts the perception of tone ceases; and the question arises whether this limit is based upon processes in the peripheral mechanism of the ear or is of central origin. A second problem in regard to tones of low frequency is the prominence of harmonics, and the place of origin of these in the acoustic system. In general, it is of interest to inquire to what extent the response of the ear to low tones resembles that to the more common range of frequencies.

Method and Procedure

This paper presents results on the action of low tones on the ear of the guinea pig, as revealed by the electrical responses of the cochlea. During stimulation with tones of definite intensities, the responses from the round window were led off by suitable electrodes, amplified, and recorded by means of a cathode ray oscillograph. For details of the operative procedure and recording method, the reader is referred to a previous publication.[1]

The tones used were of the following frequencies: 5, 10, 15, 20, 30, 40, and 60~. They were produced by a pistonphone. A small piston in a thick-walled cylinder was driven in simple harmonic motion by a variable-speed motor acting through a crank mechanism. The speeds of the motor, and hence the frequencies of the generated sounds, were accurately controlled with a stroboscope. Fig. 1 shows a schematic diagram of the pistonphone and the accessory apparatus of the pressure system.

Following the pistonphone a hose made connection successively with an acoustic filter, a volume chamber, a second acoustic filter, and finally with the external meatus of the animal's ear. To avoid loss of energy, the hose was of the pressure type, with heavy, cloth-insertion walls, and care was taken to make all connections air-tight. The connection with the meatus of the animal's ear was made by sewing in a specially fitted cannula.

[1] E. G. Wever and C. W. Bray, The nature of acoustic response: the relation between sound intensity and the magnitude of responses in the cochlea, J. Exper. Psychol., 1936, 19, 129–143.

The acoustic filters were necessary to eliminate high-frequency noise caused by vibrations of the motor and driving mechanism. The first of these was a 5-section, low-pass filter designed to attenuate frequencies above 100~.[2] The second was a 90 cm length of soft rubber tubing, which gave considerable attenuation of frequencies above 3000~. The insertion of these two filters produced a loss of only about 1 db for the low tones, which is considered negligible. Some additional filtration was afforded by the volume chamber, which acted as a Helmholtz resonator. The total filtration was such that at the terminus of the system no motor noise was audible to the human ear.

The sound pressure at the ear of the animal was controlled by varying the total volume into which the pistonphone worked. Calculations of the necessary volumes were made by the following formula,

$$p = \frac{kRAP_0}{\sqrt{2}V},$$

where p = desired pressure in bars (root-mean-square dynes per square cm), k = ratio of specific heats for air (= 1.4), R = radius of the crank, or the maximum amplitude of the piston stroke, A = area of the head of the piston, P_0 = atmospheric pressure (= 10^6 bars), and V = average volume of the total enclosure.[3] A number of volume chambers were used to give intensities in steps of 5 db from 10 to 60 db above 1 bar.

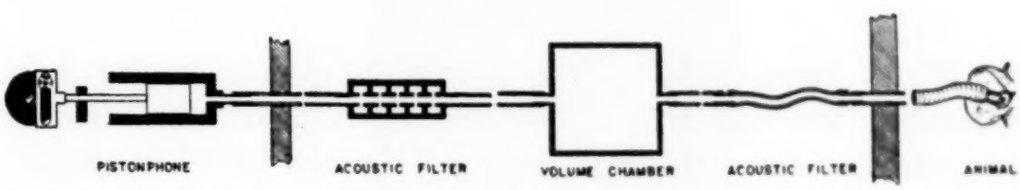


FIG. 1. The pistonphone and associated apparatus. The pressure system occupied two rooms, and ended at the animal in a soundproof room. The scale varies.

The amplifier and oscillograph were the same as used in previous experiments, with slight modifications. The sensitivity was constant within 1 db from 60~ upwards, but fell off somewhat for the lower frequencies. It was down 1 db at 30~ and 2 db at 15~. Since apparatus was not available for producing electrical currents of pure sine form below 15~, exact data cannot be given on the sensitivity for 5 and 10~, but extrapolation of the amplification curve indicated that at 10~ the sensitivity was 3 db and at 5~ it was 4.8 db below that at 60~. The absolute values of response reported in this paper for 5 and 10~ are therefore based upon these extrapolations, and are subject to slight error; we believe that this error does not exceed 2 or 3 db. Calibration between 15 and 60~ was done by two methods, by means of an electric oscillator and by means of a microphone operated by the sounds from the pistonphone. These methods yielded

[2] For the theory of such filters, see G. W. STEWART, Acoustic wave filters, *Physical Rev.*, 1922, **20**, 528–551. In a recent paper, Békésy describes methods for low tone production, with a different and very ingenious means of sound filtration; see G. v. BÉKÉSY, Über die Herstellung und Messung langsamer sinusförmiger Luftdruckschwankungen, *Ann. d. Physik*, 1936, **25**, 413–432.

[3] In this formula, loss of energy due to heat conduction through the walls of the cylinder has been neglected. The error arising from such loss is probably less than 1 db. See STUART BALLANTINE, Technique of microphone calibration, *J. Acoust. Soc. Amer.*, 1932, **3**, pp. 339 f.

results which agreed within 0.7 db or less. At the same time, the recording system was checked for linearity of intensity response and fidelity in the reproduction of wave form. The second method checked also the purity of the stimuli from the pistonphone.

The measurements of cochlear response were in terms of maximum amplitude of the waves on the cathode ray oscillograph, observed either directly or in photographs. Such measurements are valid so long as the waves in question are of sine form, but they become difficult to evaluate when the responses are of irregular form. This limitation must be borne in mind in regard to the results here reported, since the responses obtained for high intensities of stimulation were considerably distorted. An analysis of the response waves, which is now under way, will remove this limitation.

Observations were made on 9 guinea pigs. In most cases, all of the 7 tones mentioned above were presented at each of the 11 intensities. The order of presentation of the stimuli varied for different animals. Sometimes a given tone was presented at successively different intensities, and at other times the intensity was kept constant while each of the 7 tones was given; the results were the same so long as no damage was done to the ear. It was soon found that the highest intensities, 50 db (316 bars) and above, caused in some animals a marked loss of response, and care was therefore taken to explore all tones at the lower intensities before risking the destructive action of the high intensities.

Results

Wave Form.—The form of the response varied considerably for different conditions. In most animals, the responses to 5 and 10˝ were greatly distorted for all intensities of stimulation, due to the introduction of harmonic frequencies. In animal No. 7, however, the responses to these frequencies showed only a moderate departure from sinusoidal form, except at the higher intensities, where the distortion was considerable. The responses to 15˝ likewise varied. In some animals they were composed chiefly or wholly of harmonics for the lower intensities, and as the intensity was raised the fundamental frequency entered and for a time was predominant. In other animals, the response waves were of good sine form at the low as well as the moderate intensities. The high intensities for 15˝ gave very great distortion of wave form in all cases. The responses to 20˝, 30˝, 40˝, and 60˝ were of good wave form at low and moderate intensities but became greatly distorted at high intensities.

The level of intensity at which distortion entered for the tones between 15 and 60˝ was usually around 25 to 35 db above 1 bar, but this level varied for different animals and for different tones for the same animal. Table I shows the

TABLE I

Stimuli	Animal No. 6	Animal No. 7	Animal No. 8
15˜	30 db	35 db	25 db
20˜	20 db	40 db	35 db
30˜	35 db	45 db	25 db
40˜	30 db	40 db	30 db
60˜	30 db	30 db	30 db

levels at which noticeable distortion entered for animals 6, 7, and 8. With further increase in the intensity of stimulation, distortion became progressively worse.

The variations of wave form with frequency and with intensity are illustrated in Figs. 2–4. Fig. 2 shows response

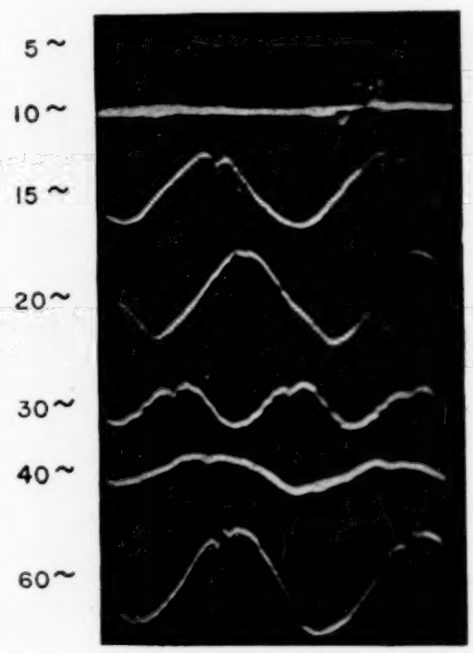


FIG. 2. Responses for different tones at an intensity of 20 db. In the 10˜ wave, *e* indicates an electrocardiogram. Animal No. 6.

waves for 5, 10, 15, 20, 30, 40, and 60˜, all at an intensity of 20 db (10 bars). For 5 and 10˜ the horizontal sweep circuit of the oscillograph was adjusted to give 1 complete wave in the photographs; for 30˜ it gave 3 waves, and for the remaining tones 2 waves. There is no visible response for 5˜, and that for 10˜ is but barely visible. The responses for the other tones are of considerable amplitude, and show reasonably

good wave form. (The small variations in these waves are due to the presence of nerve impulses, and are to be neglected for the moment.)

Figure 3 presents a series of responses for 15˜ at intensities from 15 to 60 db above 1 bar. The vertical scale varies: for the waves 25, 30, and 35 db it is 25 percent, and for those at higher intensities it is 8 percent of that used for the first

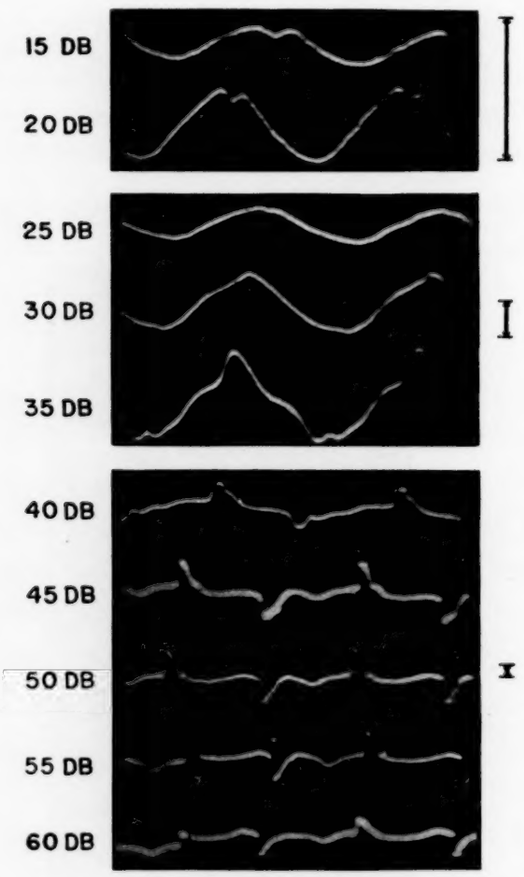


FIG. 3. Responses to 15˜ at various intensities of stimulation. The vertical scales vary for the three groups of records; the vertical lines on the right indicate, for the different groups, the deflection produced by 250 μv of response. Animal No. 6.

two waves. This change of scale was necessary in the recording, since the greater responses were attenuated to avoid overloading the final stages of the amplifier. Two complete waves are shown. The distortion becomes evident at 30 db, and is marked at 35 db and beyond.

Figure 4 shows a similar series for 60˜. The vertical scale again varies, as indicated. Distortion enters at 30 db, and

becomes gradually worse with increasing intensity. The distortion shown here is different in form from that illustrated in Fig. 3. In general, 15 and 20~ showed the 'peaked' type of distortion, and 30, 40, and 60~ the 'truncated' type. Without an analysis of the waves the basis of these differences cannot be stated, but it probably lies in differences both of harmonic composition and phase relations.

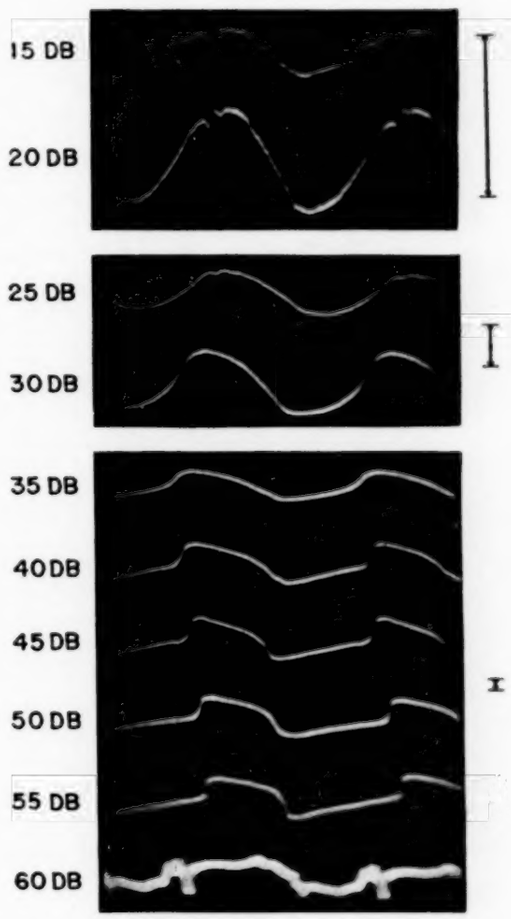
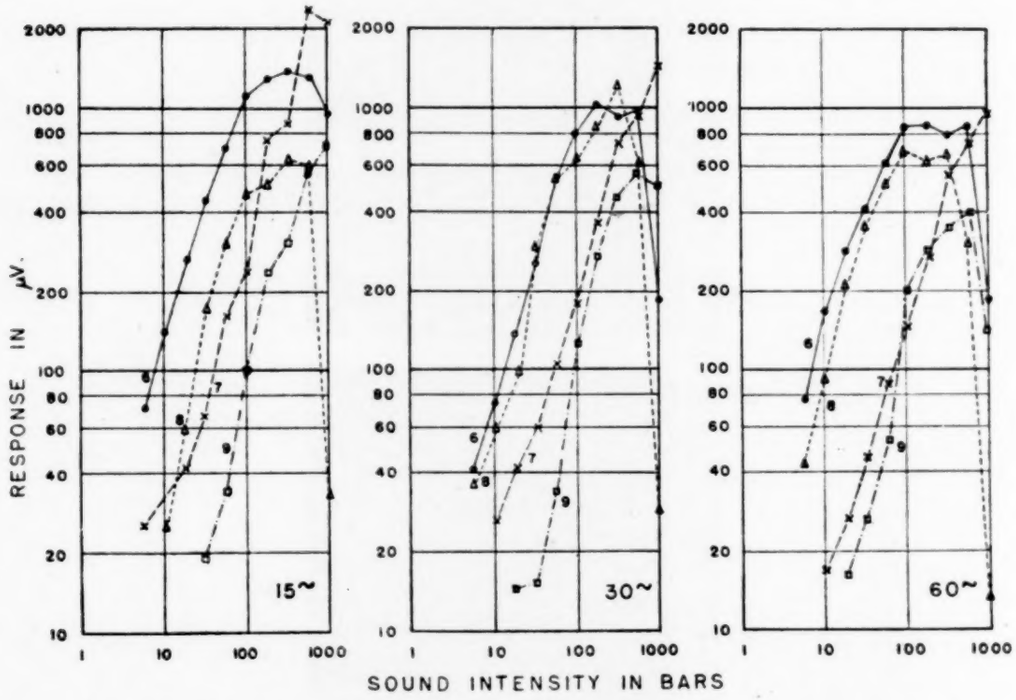


FIG. 4. Responses to 60~ at various intensities of stimulation. The vertical scales on the right indicate 250 μv, as in Fig. 3. Animal No. 6.

Relation to Intensity.—The functional relations between intensity of stimulation and magnitude of cochlear response are shown for representative animals in Figs. 5–7. Fig. 5 shows curves for four animals with a tone of 15~. The intensity of stimulation in bars is indicated on the abscissa, and the magnitude of cochlear response in microvolts (μv) is shown on the ordinate. Typically, these curves are fairly

straight for the low intensities, and bend over at high intensities. Over the lower portions, the curves have slopes similar to those previously found for frequencies between 100 and 10,000~.[4] In this figure, animal No. 8 shows a marked drop of response at 1000 bars (60 db).

Similar results for 30 and 60~ are given in Figs. 6 and 7. The general features of the curves are much the same as those for 15~. Animal No. 7 did not suffer injury by the highest intensities, as did the other three animals.



FIGS. 5-7. Intensity functions for 15~, 30~, and 60~. The numbers at the lower portions of the curves designate different animals.

The nature and locus of the injury produced by the high intensities have not yet been ascertained. Autopsies performed on some of the animals showed no destruction of the drum or obvious impairment of the ossicular chain. The only pathological features were spots of blood on both oval and round windows, and in one case on the stapedius muscle. It is possible that these were caused by hemorrhage within the inner ear, but histological study is necessary to decide this point.

[4] J. EXPER. PSYCHOL., 1936, **19**, 129–143.

Figure 8 shows results on all 7 frequencies for animal No. 8. Between 15 and 60~ there are only moderate differences in sensitivity, but a noticeable drop in sensitivity occurs for 10 and especially for 5~. For all tones the curves show a maximum of response at 100 to 316 bars (40 to 50 db), and then a rapid drop, which at 1000 bars (60 db) becomes

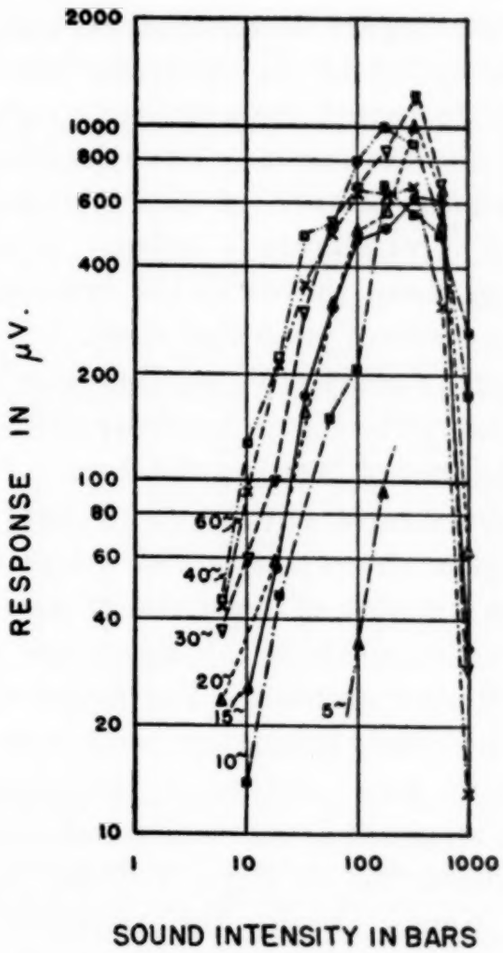


FIG. 8. Intensity functions for animal No. 8. The numbers at the lower portions of the curves indicate sound frequencies.

extreme. In this animal injury probably occurred at 562 bars (55 db).

In view of the frequent variations of wave form in the responses represented by these curves, it is rather surprising that the intensity functions are as regular as they are, for as mentioned above the values of response are peak values, calculated from the maximum amplitude of the waves. It is

evident, therefore, that for any one tone the changes of wave form are systematic functions of the intensity.

In these experiments, momentary diminutions in the responses, due to protective reflexes, were frequently observed. As Hallpike has shown and as we also have observed for higher frequencies, these diminutions are due to tetanic contractions of the tympanic muscles.[5] The reflexes were especially prominent at the higher intensities of stimulation. They were sometimes sufficient to obliterate the responses, but more often they decreased the amplitude only by a half to a third. Smaller diminutions may have occurred, but were unnoticed. A striking feature of this phenomenon was the change of wave form during a reflex. A highly distorted wave, like one of those shown at the bottom of Fig. 3, was converted into a wave of good sine form.

The variations of sensitivity for different low frequencies, which can be observed in Fig. 8, are more clearly demonstrated by a different manner of plotting the data. Fig. 9 presents a family of equal-response curves for animal No. 6. Each curve in this figure shows the sound intensity necessary to produce a given amount of response at various frequencies from 5 to 60˜. Also given in this figure are values for 100˜, taken from a different animal.[6] The figure shows the variation of sensitivity with frequency, and also with response level. There is no great change in the form of the curves with change of response level, which reflects the fact that the curves as presented in Figs. 5–8 are fairly similar in slope. As the figure shows, the sensitivity varies only slightly from 15˜ to 60˜. The maximum of sensitivity (the region where the least intensity is required for a given response), is between 15 and 20˜, with perhaps a second maximum around 60˜. Below 15˜ the sensitivity falls off with great rapidity.

Nerve Impulses.—As mentioned earlier in the discussion of Fig. 2, nerve impulses were found to accompany the cochlear

[5] C. S. HALLPIKE, On the function of the tympanic muscles, *J. Laryngol. and Otol.*, 1935, **50**, 362–369.

[6] See Fig. 5, p. 139, in J. EXPER. PSYCHOL., 1936, **19**.

responses during stimulation by low tones.[7] These appeared as sharp spikes, or groups of spikes, representing volleys of impulses. There was evidence of a threshold for these impulses. The volleys of nerve impulses varied in maximum amplitude and in the number of their component spikes. Our impression is that with increase in frequency or in intensity the spikes became more numerous, the maximum amplitude less, and the group more scattered. But whatever the form of the volleys, they always appeared in systematic

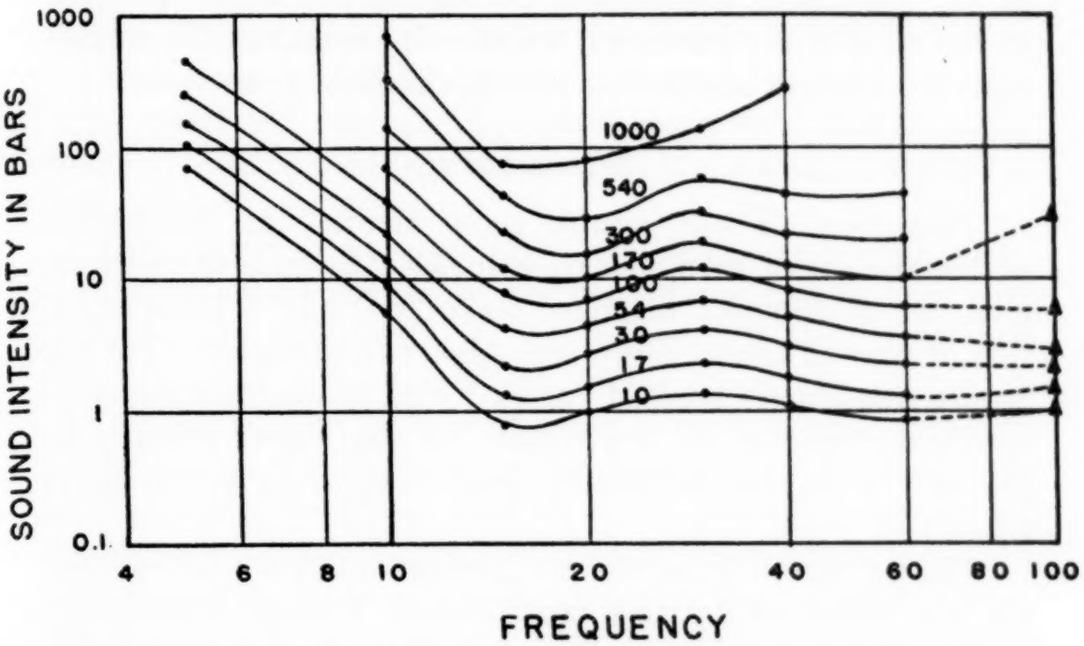


FIG. 9. Equal-response curves for animal No. 6. Each curve shows, for various frequencies, the intensity of sound necessary to produce a given magnitude of response. The magnitude of response represented by a given curve is stated in μv by the number above the curve. The values for 100 represent observations on a different animal.

relation to the wave of cochlear response. In some cases there was but one volley per wave. This appeared at the crest of the wave, at the trough, or in some intermediate position, but for a given condition of stimulation the location was constant. In other cases, there were two, three, or more volleys per wave, but an integral relation to the cochlear wave was invariably maintained. Figs. 2, 3, and 4 show these volleys as small irregularities in the curves. The

[7] Cf. A. J. DERBYSHIRE AND H. DAVIS, The action potentials of the auditory nerve, *Amer. J. Physiol.*, 1935, 113, 476–504.

photographs do not show the maximum amplitudes of these volleys, since the beam of the oscillograph was moving too rapidly to register. In Figs. 3 and 4, the volleys are not revealed for the more intense stimuli because the sensitivity of the recording system was greatly reduced, and the volleys do not increase correspondingly in magnitude with increase in intensity of stimulation. In several of the photographs one prominent volley per cycle can clearly be observed, and in some a second volley can faintly be seen also. For example, in the lowermost photograph of Fig. 2, the larger volley is at the crest of the wave, but another is present at the trough, represented by a slight blur and thickening of the trace.

Discussion

Distortion.—These results show clearly the production within the ear of harmonic frequencies. Stimuli of sine form give rise to complex response waves through a transformation of part of their energy into higher frequencies. For the lowest frequencies studied (5, 10˜) this transformation commonly occurred at all intensities; for the higher frequencies (20–60˜) it became noticeably great beyond 30–40 db above 1 bar.

The particular locus and mechanism of this transformation are not indicated by this experiment. Energy transformations of this kind are familiar in the action of mechanical systems that are overloaded, and it is easy to conceive that the overloading occurs in the middle ear, in the response of the drum and ossicles. With low tones at high intensities these structures are called upon to move over relatively great amplitudes, and distortion is inevitable. Distortion may enter also in the inner ear. As we have suggested previously, overloading may occur in the action of the sensory cells of the organ of Corti.[8] The mechanical type of distortion, which results from non-linearity in the vibratory transmission of the moving structures, should depend upon amplitude, and therefore for constant pressure should be greater the lower the frequency. A similar relation is likely for the

[8] J. Exper. Psychol., 1936, 19, pp. 142 f.

second type of distortion also. All these tones are so low in frequency as probably to involve the entire extent of the basilar membrane for all the intensities here considered. With spread of response over the basilar membrane always a maximum, there remains only amplitude of movement and hence degree of excitation of the hair cells as the variable with sound intensity. When all the cells approach their maximum of electrical output, the curve of response bends over, and finally flattens out, as shown in Figs. 5–8. Consistent with these assumptions is the absence of any tendency for the higher of these tones to reach a maximum at relatively low levels of response, which would be expected if they involved more restricted regions of action along the basilar membrane. (Such a tendency is found for high tones, as described previously.[9])

The fact that at very high intensities the curves of response pass their maximum and bend downward has not been satisfactorily explained. It will be recalled that these data are expressed in terms of maximum amplitude of the response waves, and when distortion is present such measures do not reveal the total energy (rms pressure) in the responses. It is possible, therefore, that no actual loss of energy occurs, but only a transformation into higher frequency components of such nature as to give a flattening of the response curves. An analysis of the curves will supply a test of this possibility. But an inspection of the results, such as those of Figs. 3 and 4, makes us doubtful whether this explanation will be supported. We suspect that an actual impairment of sensitivity, though a reversible one, occurred at high intensities. With yet greater intensities, as shown in several cases, the impairment became severe and irreversible. In these cases the distortion was extreme, though the response had fallen to a comparatively low level.

The Problem of the Lower Limit of Hearing.—The results of this experiment supply certain lines of evidence on the problem of the lower limit of pitch perception. Sensitivity, as shown by the cochlear response, falls off very rapidly below

[9] J. Exper. Psychol., 1936, 19, pp. 136 f.

15˜. This in itself tends both directly and indirectly to limit low tone perception. The direct limitation is obvious. The indirect limitation arises from the fact that the responses which occur to tones below 15˜ are particularly distorted; and the overtones become greatly favored relative to the fundamental. When harmonic frequencies are abundant and strong, and the higher ones among them are relatively favored in the sensitivity of the system, a decrease in fundamental frequency may cause no corresponding change in the complex of responses. Finally, it is found that for these low tones there may be more than one volley of nerve impulses per cycle of stimulus; this is characteristically true for the lower tones in the range investigated, and for the higher intensities of all tones. Such a multiple volley response does not occur for intermediate and high tones. If, as we have argued elsewhere,[10] the pitch of low tones (at least) is a function of the frequency of the volleys of nerve impulses, we have here a further explanation of the lower limit of hearing. This explanation is of course closely allied to the distortion of the cochlear response for low tones, if it can be assumed that the multiple volleys within a cycle are the direct consequence of the presence of harmonic frequencies. This assumption is the simplest one, for it explains the fact that the volleys maintain an integral, multiple relation to the stimulating frequency, but further study should be made of this question. We feel somewhat doubtful on this point because we have observed as many as two volleys per cycle for response waves, even at 60˜, that to ordinary inspection are very nearly sinusoidal.

General Implications.—If we can assume that the responses of the human ear are like those shown for the ear of the guinea pig, we can apply the results of this study to three general problems of hearing, the problems of the upper limit of loudness, the perception of subjective harmonics in tones of low frequency, and the lower limit of the perception of pitch.

The results show that for a given tone the maximum response of the cochlea may be reached at an intensity below that which produces injury. It is suggested, therefore, that a

[10] *Psychol. Rev.*, 1930, 37, pp. 376 ff., and *Physiol. Reviews*, 1933, 13, pp. 419 ff.

true limit to the loudness of sounds is established by the peripheral system, and is not simply that defined by the entrance of pain or kinesthesis or actual damage to the ear. Of course, limitations beyond those shown by the cochlear response may be introduced in the nervous processes that follow.

The prominent distortions of wave form in the cochlear responses, and the appearance of multiple volleys of nerve impulses, indicate a peripheral origin of the subjective harmonics of low tones of high intensity. Likewise, the multiple volley responses limit the transmission of low frequencies and thus impose in the peripheral system a lower limit of hearing.

Summary

The ears of guinea pigs were stimulated with sine waves of frequencies between 5 and 60^{-} and intensities from 10 to 60 db above 1 bar. The electrical method was used to study the cochlear responses and nerve impulses from the round window. For the lower tones the waves of cochlear response were characteristically distorted; for the higher tones they were sinusoidal at low intensities and distorted at high intensities. The greatest intensities were sufficient to damage the ear. The functional relations between stimulus intensity and the magnitude of cochlear response were similar to those previously found for higher tones. Sensitivity was very low to tones below 15^{-}, but from that frequency upward was fairly uniform. The volleys of nerve impulses always bore a simple integral relation to the waves of cochlear response. The results are discussed in regard to the problems of the upper limit of loudness, the origin of subjective harmonics, and the lower limit of pitch perception.

(Manuscript received August 3, 1936)

REACTIONS OF NEWBORN INFANTS TO THERMAL STIMULI UNDER CONSTANT TACTUAL CONDITIONS

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I. Introduction

Few experiments under controlled conditions have been made on responses of newborn infants to thermal stimuli.

Genzmer (**5**) touched various parts of the body of 20 infants with an ice-cold iron rod and blew on wet portions of the skin. When the rod was applied to the sole of the foot it was withdrawn; when applied to the hollow of the palm, the hand closed and then withdrew; when the cheek was cooled the head turned to one side.

Preyer (**16**) gradually lowered the temperature of the bath water of an infant. He reports that the water could be lowered to 32.5° C. without 'lessening the child's pleasure,' but when reduced to 31.25° C. the child 'screamed uninterruptedly until warmer water was added.' He assumes a skin temperature of about 32° C. He also observes that if milk or water were a little above blood temperature or a few degrees colder than the breast milk the infant refused it. However, a child can easily *learn* to take liquids at room temperature if they are always given at that temperature.

Peterson and Rainey (**13**) observed the reactions of 1060 infants to various sensory tests. Temperature experiments were limited to observations made while the infants were being bathed. Reactions were obtained on the first day in a large number of premature as well as full term infants. The responses mentioned are shivering, crying, and movements of the trunk, legs, and arms.

Canestrini (**2**) for temperature stimulation employed alcohol, ethyl chloride, pieces of cold metal, and blowing on the face. Change of brain volume, as shown by the large

fontanelle, and of respiration together with the reaction time were recorded on a smoked drum. A cold stimulus resulted in a stronger and more immediate response than pain or other tactual stimuli, as evidenced by heightened brain volume, irregularity and increased depth of respiration, restlessness, and a more rapid pulse rate.

Kashara (**9**) investigated the suction response of 2 infants to bottle feeding. Sucking became irregular when the temperature of the milk was below 20° C. or above 40° C. The suction curve was always regular and never discontinued when the temperature was between 30° C. and 40° C.

Blanton (**1**) reports marked shivering of newborn infants within 15 minutes after birth, which persists sometimes until the infant is brought near a hot water bottle. Exposing the lower part of the infant's body to the heat of a mild fire causes curling of the toes both upwards and downwards.

Peiper (**12**) used 3 premature infants (term not given), one 3 days old, the others 14 days old. Cold water was run through a metal capsule placed on the abdomen, water of body temperature having previously filled it. Respiration changes were recorded on a smoked drum. Peiper reports that the infant reacts rapidly and violently and often cries loudly, showing the disagreeable nature of the stimulus. A 13-month old microcephalic child gave the same results.

Pratt, Nelson, and Sun (**14**), employing 30 infants from birth to 21 days, used chilled metal cylinders ranging from 5° C. to 20° C. on the forehead and the inside surface of the knee. In a second experiment, water of the following temperatures was dropped into the mouth: 8°, 13°, 18°, 23°, 33°, 43°, 48°, and 53° C. The physical factors in the environment were carefully controlled. Reactions were recorded by protocol and stabilometer. The most frequent reaction to metal cylinders placed on the forehead was throwing back the head. Sleeping infants gave a slightly greater number of reactions than those awake. The infants reacted 87 percent of the time to water being dropped in the mouth. The percentage of reactions decreased with age up to 10 days and then slightly increased. Of the specific movements recorded

23 percent were sucking movements (possibly due to tactual stimulation as well as temperature), 19 percent movements of the extremities, 19 percent general bodily movements, 13 percent head movements, 12 percent facial movements, 8 percent mouth movements other than sucking, 4 percent mouth sounds, and 2 percent eye movements. The percentage of specific movements roughly increased in direct proportion to an increase in temperature from some point between 33° C. and 43° C. The infants reacted less strongly to temperatures above body temperature (assumed to be 37° C.) than below.

Pratt (**15**) studied the relation of general temperature and humidity conditions to the activity of about 70 infants from birth to 15 days old, employing the same method and control as Pratt, Nelson, and Sun. Environmental temperatures ranged from 74° F. to 88° F.; humidity was 22 percent to 90 percent. Increased temperature caused a slight decrease in the amount of time an infant engages in bodily activity involving shifts in bodily position. Humidity had slight, if any, effect.

Jensen (**8**) employed a modified Robert's manometer in recording the suction reactions to temperature during bottle feeding. Seventeen infants were studied from birth to 12 days. The threshold at which the sucking responses to heated or cooled milk differed from that to milk at 40° C. was noted. The upper temperature threshold ranged from 50° C. to 65° C.; the lower, from 5° C. to 23° C. There were large individual differences, but the threshold for any individual tended to remain the same. Differential reactions to 55° C. and 15° C. in 8 infants were obtained as early as the second day. In 12 infants certain differential reactions to temperatures above 50° C. were found to be identical with certain differential reactions below 23° C. Differential reactions gradually deviated from the control curve. He found, in threshold determinations, reaction times as long as 6 to 8 seconds before the differential reaction began.

The experimental techniques thus far used in studying temperature reactions of newborn infants fall into four

different classes. (1) The employment of the food-taking response as used by Kashara and Jensen. (2) 'Bath water' or some similar medium where the stimulation is over a large, indefinite area as used by Preyer, Peterson and Rainey, Blanton, and Pratt. (3) Stimulus limited to a definite area but involving simultaneous tactual stimulation as in the methods of Genzmer, Canestrini, and Pratt, Nelson, Sun. (4) Peiper's capsule method which leaves the tactual factor relatively *constant* throughout the experiment, provides for stimulating a definite area for any length of time at a constant temperature, and offers a wide range within which any temperature can be immediately changed to any other temperature without disturbing the subject. For these reasons a modification of Peiper's method was adopted in the present investigation.

II. Apparatus and Procedure

The stimulating apparatus consisted essentially of a round brass capsule 23 mm in diameter with an inflow and outflow tube through which water of various temperatures might flow from a gravitation system. Reactions were recorded by motion pictures and protocol.

Three five-gallon thermally insulated tanks were filled with water 50° C., 35° C., and 15° C. respectively. The hot and cold waters were led by rubber tubes to a valve where they might be mixed to any desired temperature, and thence to a three way cock. Thermometers placed in the lines of the hot and cold waters indicated their respective temperatures before mixture, and a thermometer between the mixing valve and the cock indicated the temperature of the resultant mixture. The cock was so connected that the mixed water could be turned into the capsule line or go off as waste. The neutral temperature tank was also connected by a rubber hose line leading to a three way cock which led the water either into the capsule line or off as waste. A thermometer inserted into this line gave the temperature of the water flowing from the tank. The line leading to the capsule was connected to the neutral and mixed water lines by a Y-tube.

The temperature of the water at the capsule was indicated for photographic purposes by a large dial on which lines were placed indicating half degrees from 16° C. to 60° C. This dial was operated by O. who recorded the temperature changes from a thermometer placed in the capsule line immediately before the line leading to the infant's crib. Since the maximum thermal loss between this thermometer and the capsule was found to be .25° C. no attempt was made to calibrate this loss for the various temperatures used. Thermometer lag and rate of flow of the water were measured and these factors considered in studying the results.

The motion picture camera was driven by a constant speed motor and mounted in a sound-proof box which reduced the noise when the camera was in operation to a low hum that was barely audible at the crib. At no time did the noise of the camera have any observable effect on the infant. Lighting was indirect.

A word might be said here concerning a neutral temperature. There are few systematic studies which report the physiological zero of newborn infants, *i.e.*, whether it is constant or fluctuating, and whether it is the same for every part of the body. Preyer presumes it to be near 32° C. Peiper writes of using water of body temperature but does not state what that temperature is. Pratt, Nelson, and Sun assume it to be 37° C. but do not state their method of determination. Jensen apparently assumed 40° C. In the present study the 'neutral' was 33° C. to 34° C. The reason for selecting this temperature is for comparison with experiments on adults within a similar range. Furthermore, in various preliminary trials, it was carefully noted that this temperature produced, in and of itself, no observable changes in the sleeping infant's behavior.

The procedure was as follows: The sleeping infant was placed in the crib and the capsule through which neutral water had been continuously flowing was carefully fastened to the dorsal surface of the leg, midway between the foot and the knee, by means of one thickness of gauze bandage. In a preliminary experiment three different capsules (10 mm, 23 mm, and 60 mm in diameter) were applied to the infant's chest. Marked and abrupt respiratory changes and abdominal movements were obtained with all three capsules. Due to the difficulty, however, of recording the kind and extent of localized movements in this region, the leg was selected as a more suitable spot for determining overt responses. Only the 23-mm capsule was used on this area. The 60-mm was too large, and the 10-mm capsule had a tendency to tilt because of the tubes leading water to and from it. This not only caused an uneven pressure on the skin surface, but raised some doubt as to whether the whole lower surface of the capsule was touching the skin at all times.

After the capsule was attached a period of a few minutes was allowed for S. to become adjusted to his environment, the criterion being continued quiescence, regularity of respiration, and a general appearance of sleep. The mixing valve was then adjusted to the desired temperature, the mixed water being allowed to flow off as waste. The camera was started by the recorder (who also took protocol), and a few seconds later the neutral water was turned from the capsule line and the mixed water turned simultaneously into it. O. indicated the temperature changes in the capsule by moving the dial in response to changes of the capsule-line thermometer.

With the last four subjects (J, K, L, and M) the following procedure was added to obtain an approximate measure of the reaction time. The thermometer in the capsule line responded almost immediately after water of a changed temperature had passed that point, but took 18 seconds or more to record the actual temperature of the water flowing into the capsule. Therefore upon the beginning of the thermometer change, O. immediately turned the dial in the direction of the change to make final adjustments when the thermometer recorded the actual temperature of the water. The time necessary for the water to flow from the thermometer to the capsule subtracted from the time elapsing between the first movement of S. gave an approximate measure of the reaction time.

After S. had reacted and become again quiescent (asleep), and if it appeared that no further movements would follow the particular stimulus, the water was changed back to neutral in the same manner described above. Two or three changes of different range and their corresponding returns to neutral were given to each infant during the experimental period.

A possible small change in water pressure as the cocks were turned from neutral to another temperature or back again might have caused a different tactual sensation. This was checked as follows: the tube leading to the capsule was pinched sharply,

resulting in a sudden rise in water pressure. In no case did this produce a reaction in the infant.

That occasional slight shifts of the capsule occurred during the reaction, especially in violent responses, is fully recognized. Gauze bandage, rather than a firmer adhesive tape, was selected, however, because of its light porous nature and lack of skin irritation.

The experiment was carried on during morning hours in the Maternity unit of the University of Michigan Hospital in a well isolated room with temperatures ranging from 27.5° C. to 33.5° C., during the total period of experimentation.

III. Results

Direction and Range of Temperature Changes: The results here given are for 9 infants, 6 of whom range from 41 to 100 hours in age (Subjects K, H, G, L, F, and M), one of 151 hours (Subject J), one of 371 hours (Subject C), and one, a $7\frac{1}{2}$-month premature, of 1045 hours of age (Subject D). All were of normal spontaneous birth and, excepting one, were full term infants. Of the group, 5 were females and 4 were males. Three were negroes, six were white. A total of 36 temperature stimulations was used.

For the purposes of this study the following items have been emphasized: (1) Number of responses as related to the different degrees of thermal stimulations. (2) Kind of response patterns, *i.e.*, 'mass,' 'segmented' or 'localized.' (3) Sequence of response patterns. (4) Magnitude of response. (5) Gross reaction times. Record of response patterns was made by frame-by-frame analysis of the cinema records. The temporal sequence was denoted by numbers, the first pattern of movements arising being denoted as 1, the second 2, etc., and the magnitude of each response as of slight (*X*), moderate (*Y*) and extreme (Z). When a number of responses of different parts of the body occurred at the same time all were given the same numerical ranking in sequence but were graded separately in magnitude. Thus, if the first responses were a moderate contraction of the stimulated leg and a simultaneous violent extension of the other leg, this reaction was designated: "Same leg contracted 1-*Y*, opposite leg extended 1-Z," the number being the temporal sequence, and the letter the degree of amplitude. If these responses were followed by a slight extension of the stimulated leg the latter would be designated "Same leg extended

2-*X*." When a response continued as other responses arose, it was given the numerical sequence of the temporal pattern in which it first appeared and was ranked in amplitude according to its total reaction period. For example, if the stimulated leg extended first but while it was moving, the head also moved, the designation was "Same leg extended 1, head 2." If the stimulated leg were fully extended from a contracted position close to the body and the head turned slightly, the complete designation would be "Stimulated leg extended 1-*Z*, head moved 2-*X*."

Since the temperature changes were always in terms of deviations from neutral (33°–34° C.) the following nomenclature will be used to indicate direction of change:

Neutral to lower = $N - l$(ower)
Lower to neutral = $L - n$
Neutral to higher = $N - h$(igher)
Higher to neutral = $H - n$

The amount of temperature change will be designated by the actual number of degrees difference between N (whether it is 33° or 34°) and the stimulation other than N. Thus a fall from N at 33° to 27° C. will be indicated as $N - l$, 6°.

Table I gives the number and magnitude of all responses to each temperature stimulation. Examination of this table shows the following general facts:

1. In all cases responses to temperature stimulations were obtained, although these responses sometimes differed in pattern and magnitude. This is not in accord with Pratt, Nelson, and Sun (**14**), who found responses to only 87 percent of the stimulations. In two cases in this experiment, however, the response was so slight that only careful analysis of the film revealed its presence. Possibly some of Pratt, Nelson, and Sun's 'no-response' cases were of this minimal type.

2. Responses were obtained in 2 cases to differences as small as 5° C., and in 4 cases to differences as small as 6° C. It is probable that reactions to still smaller changes occur, but no attempt was made to use them in this study.

TABLE I

S	*TA*	*X*	*Y*	*Z*	*L*	*N*	*To*	*TR*	*X*	*Y*	*Z*	*L*	*N*	*To*
C	34–45	1	7	22	9	21	30	45–34	8	13	0	4	17	21
D	34–45	5	7	5	3	15	18	45–34	3	0	0	2	3	5
G	33–44	24	7	5	16	20	36	44–33	12	8	5	10	15	25
	Total	30	21	32	28	56	84	Total	23	21	5	16	35	51
F	33–40	2	4	2	4	4	8	40–33	8	4	11	12	13	25
H	33–40	2	0	0	0	2	2	40–33	7	1	0	4	4	8
J	34–40	1	4	1	2	7	9	40–34	3	6	2	2	10	12
K	34–40	3	8	2	4	9	13	40–34	6	2	2	5	5	10
L	34–40	5	1	0	4	2	6	40–34	2	2	8	4	8	12
M	34–40	2	3	0	2	3	5	40–34	0	2	0	2	0	2
	Total	15	20	5	16	27	43	Total	26	17	23	29	40	69
H	33–20	9	5	2	6	10	16	20–33	7	3	0	0	10	10
K	34–20	2	9	0	4	7	11	20–34	8	3	3	5	10	15
L	34–20	16	8	0	10	14	24	20–34	8	9	5	11	11	22
	Total	27	22	2	20	31	51	Total	23	15	8	16	31	47
J	34–25	3	4	5	3	9	12	25–34	13	7	1	7	14	21
G	33–26	19	11	9	11	28	39	26–33	2	0	2	0	4	4
H	33–27	5	12	2	7	12	19	27–33	10	2	0	2	10	12
F	33–28	0	4	1	0	5	5	28–33	0	1	1	1	1	2
	Total	27	31	17	21	54	75	Total	25	10	4	10	29	39
C	34–16	4	10	4	5	13	18							
D	34–20	2	6	6	8	7	15	No corresponding ascending stimulus situations						
F	33–20	5	9	17	9	22	31							
G	33–21	26	3	4	10	23	33							
	Total	37	28	31	32	65	97							

Explanation

S—denotes the subject.

TA—range of temperature stimulation going away from neutral.

TR—range of temperature stimulation returning to neutral.

X—number of responses of slight amplitude.

Y—number of responses of moderate amplitude.

Z—number of responses of great amplitude.

Responses which were partly hidden from the camera leaving the amplitude classification in some doubt are included in *L* and *N* but not in *X*, *Y*, or *Z* columns. A total of 21 such responses are recorded.

L—number of localized responses.

N—number of non-localized responses.

To—total number of responses to any one thermal stimulation.

3. In comparing the number of responses made to $N - l$ and $N - h$ stimulations, 3 facts seem apparent. (*a*) There is a marked excess of the number and magnitude of responses

in the $N - l$, 5°–8° stimulations as compared to the $N - h$, 6°–7°. That is, newborn infants seem to respond to a lowering of temperature more violently than a raising of temperature of approximately the same number of degrees. This is in accord with Pratt, Nelson and Sun's findings (**14**) that "The infants reacted less strongly to the temperatures which are warmer than body temperature than to those which are colder" (p. 167).

(*b*) That large individual differences exist among newborn infants. For example, subject G gives 39 responses to $N - l$, 7° while subject L of the same chronological age (70 hours) gives only 24 responses to $N - l$, 14°.

(*c*) That in the $N - l$ stimulations there seems to be little relation between the number and magnitude of responses and the degree of thermal stimulation. Thus subject F gives, in response to $N - l$, 5° five responses, one of which is of extreme magnitude and to $N - l$, 13° thirty-one responses, seventeen of which are of extreme magnitude. On the other hand, subject H gives to $N - l$, 6° nineteen responses, two of which are of extreme magnitude and to $N - l$, 14° only sixteen responses with two of extreme magnitude. The above is not in accord with either the results of Pratt, Nelson, and Sun (**14**), or Jensen (**8**). Pratt, Nelson, and Sun find, in a temperature range corresponding to the one used in this work, that of the specific movement groups, 16 percent are to 18° C., 14 percent to 23° C., and 9 percent to 33° C.

Jensen says: "The differential reactions secured were not of all or none character, but proved to be gradual deviations from the control curves, becoming more marked as the experimental temperatures were raised or lowered as compared with the controls" (**8**, p. 467). It is possible that a greater number of stimulations would yield a trend of results similar to those of the above authors.

The $N - h$ stimulations in our data cannot be compared in a similar manner.

4. Comparing the $N - h$ series with the $H - n$ series (11° and 12° range) the $N - h$ series shows a marked excess in the number of responses as compared to the $H - n$ series.

If the stimulus range is reduced to 6° or 7°, however, the results become variable, and in 4 instances reversed. For example, subject M gives 5 responses to $N - h$, 6° and 2 responses to $H - n$, 6°, but subject L gives only 6 responses to $N - h$, 6° while $H - n$, 6° results in 12 responses.

5. Comparing simply the $N - l$ series with the $L - n$ series, the $N - l$ stimulations show a greater number of responses than the $L - n$ series. This is true in 5 of the 7 situations. The remaining 2 show an increase in response in the $L - n$ stimulations.

6. Excluding these few exceptions, however, which seem related to the reduced temperature range, the total number and magnitude of all responses to all stimulations where there is a corresponding return to neutral are greater going away from neutral than when returning to it.

These data indicate that regardless of the direction of the temperature change *any deviation from neutral produces immediate and marked responses.* They also seem to indicate (as shown by the total number of responses to any stimulus situation) an extremely rapid adaptation to any 'new' temperature regardless of direction.

A possible explanation of the difference in number and amplitude of responses 'away from' and 'towards' neutral, dependent on the assumption that there is a differential response to different ranges of stimulation, is suggested by the work of W. L. Jenkins (7). He found in the stimulation of isolated cold spots in adults that "All types of (cold) stimulation, continuous and intermittent, produce qualitatively the same effect, a long-lasting depression of the liminal level" (p. 19). As interpreted by our data, it would appear that a thermal stimulation going from neutral to some other point and continuing there until adaptation results will shift the neutral point in the direction of the change just as more general physiological changes, viz. fever, shift the neutral or physiological zero. The 'return' from that point to the *original* neutral temperature would thus be a stimulation from some point on one side of the 'new' neutral to some point on the other side. The return therefore must pass

through a region of sameness (where a thermal stimulation differing slightly from neutral would give no response other than as given by neutral) on both sides of the 'new' neutral point, whereas the 'away-from-neutral' stimulation passes through this region of sameness only on one side of the neutral point. Hence in the return-to-neutral stimulation the apparent thermal change is not so great, resulting in fewer responses. The exceptions (as stated earlier) may have occurred because of less adaptation and the resultant 'constancy' of the original neutral.

The results obtained from the $N - h$, 6° represent relatively small deviations from neutral, and hence are close to this region of sameness. Why, however, the same approximate deviation from neutral on the cold side ($N - l$, 5°, 6°, and 7°) yields results similar to greater deviations from neutral and dissimilar from the $N - h$, 5° and 6° stimulus situations is a matter of speculation. Possibly the solution may be found when the characteristics of the true physiological zero and the thermal influence of surrounding areas on a stimulated area in the newborn are known. The above is only given here as a suggestion and is not to be regarded as a full explanation.

Mass Reaction, Segmental Sequence, Localized and *Non-Localized Responses*

A. Mass Reaction.—The different responses found in the mass reaction and the relative number of times each response occurred expressed in percentage of the total number of responses is as follows:

1. Respiratory and circulatory changes—present in all subjects in all stimulations.
2. Trunk responses, 2.52 percent
3. Limb responses
    - *a.* arms, 20.50 percent
    - *b.* hands, 1.44 percent
    - *c.* fingers, 2.16 percent
    - *d.* legs, 42.80 percent
    - *e.* feet, 11.69 percent
    - *f.* toes, 4.32 percent

4. Head responses
   - *a.* head turned, 7.01 percent
   - *b.* facial movements, 2.88 percent
   - *c.* eye lids (open and shut), 3.78 percent
   - *d.* mouth movements, .72 percent
   - *e.* vocalization, .54 percent

These response patterns were classified in terms of laterality, contraction *vs.* extension, and the temporal elements of simultaneity or segmented succession.

Examination of the above shows that more than half of the total number of responses made are of the legs, feet and toes, that is to say, in the general region of that portion of the body stimulated. More detailed analysis of these responses will follow.

B. Segmental Sequence, Localized and Non-Localized Responses.—1. A total of 556 specific responses (other than respiratory and circulatory) were made to 36 temperature stimulations. These responses occurred in from 1 to 23 patterns of segmental sequence. The responses to 58.6 percent of the temperature stimulations are confined to the first 8 patterns. The first 13 patterns include 90 percent of all responses made, that is, 90 percent of all responses to stimulations had terminated within the first thirteen patterns of segmental sequence.

2. Localized responses are defined as movements of the stimulated leg, any of its members (the foot or toes) or the 'scratch' type of response to be described later. A comparison of localized responses found in each pattern of segmental sequence shows a range of 0 percent in the 23d pattern to 60 percent in the 21st. However, the total number of all responses for any pattern beyond the 13th is so small (9 or less) that they are highly unreliable. The range of the total number of all responses, both localized and non-localized for any segmental pattern from the 1st to the 13th inclusive is 16 responses in the 13th to 65 in each of the 2d and 3d patterns of temporal sequence. The percentage of all *localized* responses in the first thirteen groups shows a range of from 23.8 percent in the 11th pattern to 44.0 percent in the 10th.

The first 3 patterns of temporal sequence show percentages of 36.7, 30.8, and 33.9 respectively, which is not significantly different from the total percentage of all localized responses of all patterns (33.8 percent). From a comparison of the localized responses in each pattern of temporal sequence there appears to be no special place in the temporal course of the total reaction where localized responses are most likely to occur. Certainly localized responses do not seem to appear oftener as initial responses than as later ones. The irregularity of the percentages of the patterns of temporal sequence occurring later in the total response seem to indicate that these percentages are chance results rather than that any localized responses occur consistently at any particular place in the total response. An examination of the position of occurrence of the localized responses in the total response situation of each subject to each stimulation likewise verifies this statement. These data, therefore, neither confirm nor dispute the different interpretations of Coghill (**3**) and Minkowski (**10**).

3. When all localized movements are graded in terms of the 3 degrees of magnitude, 42.55 percent are 'slight,' 38.29 percent 'moderate,' 18.08 percent 'extreme' and 1.06 percent unclassified. The greatest number of 'slight' localized responses occurred in the fourth pattern of temporal sequence, the greatest number of moderate magnitude in the first pattern, and the largest number of 'extreme' in the third and sixth pattern of temporal sequence. There appears to be *no* definite relation between amplitude and temporal sequence with regard to localized responses. Likewise it appears that those localized responses which involve simultaneous bilateral movement are less likely to be of extreme magnitude if they occur as initial responses than if they occur later.

4. The relative percentage of localized responses *not* involving simultaneous bilateral responses in terms of the total number of responses of any particular pattern of temporal sequence in order of their frequency is: sixth pattern, 85.82 percent, first and fourth, 82.61 percent, fifth, 80 percent, and third, 72.73 percent. The second pattern had only 50

percent. Since all of these groups, excepting the second, are well above the total percentage of unilateral localized responses (60.70 percent) in terms of the total number of all localized responses it is evident that a localized response of simultaneous bilaterality is less likely to occur in the initial stages of the total response situation than later on.

5. Of the unilateral localized responses 47.32 percent were of 'slight' magnitude, 38.94 percent of 'moderate,' 12.97 percent of 'extreme' magnitude, and .7 percent unclassified. The most frequent occurrence of responses of 'slight' magnitude was in the third and fourth patterns of temporal sequence, of 'moderate' magnitude in the first pattern, and of 'extreme' magnitude in the sixth pattern. Neither the first or second pattern had any responses of extreme magnitude that did not involve simultaneous bilateral movement.

6. Of all responses 66.2 percent were non-localized. The frequency of occurrence of these responses in the first six patterns of temporal sequence, expressed in terms of percentage of the total number of responses for each pattern are, first 63, second 69, third 66, fourth 57, fifth 72, and sixth 64 percent.

7. Of the specific non-localized responses 41.84 percent were of 'slight' magnitude, 30.97 percent of 'moderate,' 24.72 percent of 'extreme' magnitude and 2.44 percent unclassified. Comparison shows that the non-localized responses tend to be of greater magnitude than the localized as a whole. The non-localized responses, however, tend to be of smaller magnitude than the localized if compared specifically with simultaneous bilateral responses. The greatest number of non-localized responses of 'slight' magnitude occurred in the second pattern of temporal sequence, those of 'moderate' magnitude likewise in the second pattern, and those of 'extreme' magnitude in the first pattern of temporal sequence. Further comparison with regard to magnitude and temporal position shows 12 non-localized responses of 'extreme' magnitude to one localized response (bilateral) of the same magnitude in the first temporal pattern. In fact no unilateral localized responses of 'extreme' magnitude occurred

in the first temporal pattern at all. The same general relationship holds true in the second pattern of temporal sequence. These data indicate that those initial responses of the infant to thermal change which are of 'extreme' magnitude are more likely to be 'mass activity' than localized responses.

8. Of the localized responses involving simultaneous bilateral movement, 83 percent were responses of the legs, 12 percent of the feet and 5 percent of the toes. A total of 49 percent of these responses fell within the first six patterns of temporal sequence. Of the localized responses *not* involving simultaneous bilateral movement 59 percent were of the leg, 25 percent of the foot, 7 percent of the toes and 8 percent of the 'scratch' response. A total of 59.54 percent of the unilateral responses fell within the first six patterns of temporal sequence. It is evident that simultaneous bilateral responses most frequently involve the legs and least frequently the toes. This is likewise true in unilateral responses, although in the latter the foot is more apt to take part in the response than in the bilateral movement.

9. The specific non-localized responses in order of their frequency of occurrence are the non-stimulated leg (102),[1] the arm on the stimulated side and the head (39 each), and the arm on the opposite side (29).

The principal responses in order of their frequency are: stimulated leg extended[2] 45 responses, head movements 39, stimulated leg contracted[2] 33, opposite leg extended[2] 29, opposite leg contracted[2] 26, both legs simultaneously contracted 25, both legs simultaneously extended 22, and arm on the stimulated side contracted 22.

'*Scratch Response*': The above would seem to indicate that localization of a temperature stimulus is, to some degree, possible in newborn infants. That such may actually be the case is further shown by the 'scratch' response. This response may be described as a reaction where one leg is rigidly

[1] Includes contraction and extension responses made both alone and simultaneously with the opposite corresponding member.

[2] Responses made other than simultaneously with the corresponding opposite member.

extended and the other leg is brought up so that the foot or toes brush against the stimulated spot on the other leg (or a roughly corresponding region on the non-stimulated leg). In the oldest subject (Subject D) this reaction was so violent that the capsule, although firmly bandaged, was *repeatedly* pushed off. There is, likewise, some evidence of incomplete or incipient 'scratch responses.' This incomplete 'scratch response' is 'anticipatory' in that one leg is extended and the opposite one moved toward it in a characteristic manner, but the reaction 'fades' so to speak before the actual contact occurs.

On analyzing the circumstances in which this scratch response occurred, it is found that:

1. While not evident in every temperature stimulation, the response was found complete or incomplete in eight of the nine subjects. The exception (Subject F) was quite small and not very energetic (when born, length 34 cm, weight 3165 gms).

2. Eight scratch responses were 'complete,' and three 'incomplete.' Two of the complete responses were made on the opposite leg, *i.e.*, the opposite leg was 'scratched' by the stimulated foot. These will be designated as 'crossed' in further analysis of the results. Of the complete 'scratch' responses, one was of 'slight' magnitude (a 'crossed' response), and seven of 'extreme' magnitude. Of the incomplete, one was of 'slight' magnitude, four of 'moderate,' and one of 'extreme' magnitude.

3. These responses, both of complete and incomplete types, were produced by a variety of temperature changes. Only 1 of the 11 responses, however, was produced by changes $H - n$ and 2 by changes $L - n$. Likewise no subject gave this type of response to $N - h$, 6°–7° whereas $N - h$, 10° elicited it twice. On the other hand $N - l$, 6°–7° gave rise to 3 responses, 2 of which were incomplete and one of which was 'crossed.' It appears, therefore, that as evidenced by the 'scratch' response that infants are more likely to respond to $N - l$ than $N - h$ stimulations, but $N - l$ in a 6°–7° range is not sufficient change to give rise to a very high degree of 'localization.'

4. This 'scratch' response occurs in one instance in the second pattern of temporal sequence and once in the third. The remaining 9 cases range from the fifth to the twenty-first patterns. This further substantiates the earlier statement that specific localized responses, in general, appear to have no particular serial position in the total response.

5. There seems to be some relation between the age of the infant and the completeness or incompleteness of the 'scratch response.' The four subjects, 70 hours of age or under, gave a total of two complete responses (one of which was a 'crossed') and four incomplete. Both of the complete responses occurred with the same 70-hour-old infant (G). In the four subjects over 70 hours of age, 7 'complete' responses were made (one of which was a 'crossed'), 2 'incomplete.' Both of these incomplete occurred with the same subject (C, 371 hours old).

The parallel between Raney and Carmichael's work (**17**) on tactual localization in fetal rats and the 'scratch response' in the present study is suggestive. They found that as normal birth time approaches tactual stimulation produces a greater specificity of response in the movement of a limb so as to touch the point stimulated. That the response of the infants in the present experiment was due to the thermal change and not the tactual stimulus is fully evident in that they slept quietly and indefinitely with the capsule attached so long as the temperature remained within the 'neutral' range (33°–34°).

Organic Changes: Rapidly increased rate, irregularity, 'gasping' and other typical respiratory changes similar to those reported by Canestrini (**2**) occurred in all subjects when stimulated. Even in those cases where other movements were few and of slight magnitude the respiratory changes were quite marked even to the naked eye. These changes seemed always to appear before any bodily response of any other sort, and to continue throughout the total reaction.

Reaction Time: Reaction times to stimulation were measured in subjects J, K, L, and M by the method previously

described. When corrections were made for the time necessary for the water to flow from the thermometer to the capsule, these reaction times were found to range from 2.5 to 11 seconds with an average of 6.8 seconds. Canestrini (**2**, p. 82) gives the kymographic record of a sleeping infant who was stimulated by ethyl chloride dropped on the forehead. The infant reacted 1 second later by awakening and by strong respiratory and brain pulse changes. Jensen (**8**) on the other hand finds that in threshold determinations of sucking reactions, the reaction time may be as long as six or eight seconds. Both of these findings agree with our observations that the reaction time for organic changes is short, and that overt bodily responses are slower.

Canestrini (**2**) notes in the above infant that the total reaction time lasted only 22 seconds, when the infant returned to sleep. This is likewise in accordance with our results. All our subjects showed a rapid adaptation to changed temperature. They would usually awaken, react for a short time, relax, and abruptly fall asleep. In subjects K, L, and M, where the total duration of the reactions was measured, the length of the reaction ranged from 1/2 to 36 seconds after which there was immediate relaxation and sleep.

From these data it is apparent that Irwin's 'mass activity' (**6**) holds true for temperature stimulation. Likewise these data verify in temperature what Delman (**4**) found in tactual stimulation of newborn infants, viz., there is an inclusion of the specific localized within a larger motor pattern. Whether this is interpreted according to Coghill (**3**) as a still incomplete 'individuation' process, or as evidence of Minkowski's fetal 'irradiation' (**10**), it is the most typical response to this type of stimulation at this age level. The lessened magnitude of the single localized response as compared with the 'violence' of the mass reaction seems again to indicate some stage of incipient emergence of a specific reflex from the whole such as occurs, for instance, in the first feeble but unmistakable plantar responses of the human fetus.

The 'scratch response' appears to emerge earlier than the scratching response to tactual stimulation, as described by

Peiper (11, p. 34) who, on the basis of Szymansky's experiments, states that this response does not emerge before the second month of life when the first response arises from touching the eyelid. Stimulation elsewhere results only in 'motorische Unruhe.' According to these investigators localized responses with increasing age arise first on different parts of the face, then the trunk, and lastly the limbs. Abdominal stimulation, in a preliminary experiment of our own on a 30-day-old infant, gave rise to no localized responses other than abdominal contractions, but in a subject only 70 hours old, the 'scratch response' was fully developed.

In conclusion, this experiment indicates that thermal stimulation of the newborn infant is not a simple matter of stimulus and response, but is probably as intricate as a study of thermal stimulation in adults. Such factors as adaptation, duration of the stimulus, size and locality of the area stimulated, as well as the temperature of the stimulus, age and physiological condition of the infant are of prime importance. Likewise any study that includes reaction times and types of responses must include not only bodily movements but respiratory and as many other organic changes as possible. In addition, it would be desirable to continue the study for the first month of life or longer to obtain a developmental picture of reaction time, response patterns, and especially localizing responses. Any study must first, however, be preceded by a determination of what the actual physiological neutral point is for infants, whether it is relatively constant or not for different parts of the body, for different ages of infants, and for the same infant at different times of the day.

The results presented in this study serve to indicate some aspects of the complexity of the subject, which have not previously been studied by investigators and which do not appear in the literature. The capsule method appears to be an excellent means of attacking the problem. Suggested improvements in the present apparatus are a closed water system to make a constant rate and flow, the temperature of the water thermostatically controlled, a thermocouple

mounted in the capsule to give an exact measure of the stimulating temperature, and a more satisfactory method of changing from one temperature to another. Finally a recording system including bodily responses, respiratory and circulatory changes would be desirable.

IV. Summary

An experiment in the thermal stimulation of an area 23 mm in diameter on the leg was conducted under relatively constant tactual conditions on 9 sleeping infants ranging from 41 to 1045 hours old. A total of 36 stimulations were given, ranging from 16° C. to 45° C. The principal results summarized are:

1. With the exception of the neutral to 40° C. and 40° C. to neutral stimulations, the total number and magnitude of the responses to all temperature situations tend to be greater when the stimulation is from neutral to some other point than if it is from some other point back to neutral.

2. In all cases extremely rapid adaptation is evidenced.

3. Localized responses make up 33.8 percent of the total response pattern. There appears to be no special place in the temporal course of the total reaction where localized responses are most apt to occur.

4. On the whole, the non-localized responses tend to be of greater magnitude than the localized ones, but of less magnitude when they occur simultaneously as a bilateral localized response. Initial responses of 'extreme' magnitude are more likely to be non-localized than localized.

5. Further evidence of specific localization of thermal stimulation of the leg is shown by the 'scratch response.' There seems to be some relation between the 'completeness' of this response and the age of the infant.

It is possible that sleep in infants, as well as adults, increases the threshold of sensitivity and that subjects fully awakened might show less diffuse and more specific localized responses.

(Manuscript received September 1, 1936)

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ON THE DISCRIMINATION OF MINIMAL DIFFERENCES IN WEIGHT: II. NUMBER OF AVAILABLE ELEMENTS AS VARIANT

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Materials for the construction of laws relating sensory effect and stimulating intensity can be provided by experiments concerned with the discrimination of just noticeable differences in intensity (**4**). When properly obtained, such results may profitably be related to comparable results secured by other psychophysical methods. As yet, however, there exist neither suitable nor sufficient data for a rigorous, meaningful comparison of results secured by these methods. On the other hand, a physiological explanation can be advanced to account for results secured by any one of the methods *per se*.

In what is conventionally called the field of kinesthesis, for example, it has been demonstrated that differential sensitivity to weight, $1/\Delta W$, is a specific and reproducible function of an excitatory agent, W, in grams (**24**; **13**). A method of limits was used. For a given mode of discrimination, differential sensitivity was found to vary inversely with W (**13**). In terms of what is now called the volley theory of sensory intensity (**1**), it might be argued that $1/\Delta W$ accordingly *decreases* as the number of impulses per unit time is made to increase. However, $1/\Delta W$ has also been observed to increase as the mode of discriminating was varied from (*a*) hands passive and arms supported, (*b*) hands active and arms supported, to (*c*) arms not supported and active, respectively (**13**). Thus, differential sensitivity to weight was also found to *increase* as the number of impulses per unit of time was presumably made to increase, and it was on the basis of these conflicting results that Holway and Hurvich found it necessary to introduce a theory which makes differential sensitivity,

not a direct, but a *supplementary* measure of the number of elements (= number of impulses per unit of time) involved in the discrimination of minimal differences in weight. In simplest terms,

$$N_e + N_a = N_t, \qquad [A]$$

where N_t is the total amount of excitation per unit of time potentially available under the conditions of the experiment; N_e, the given amount of excitation; and N_a is accordingly the amount of excitation available for the discrimination in question.[1] Equations of this sort are of fundamental interest as regards investigations concerning the relation of psychophysical fact and neurological events. Equation [*A*] also has a definite implication for results to be employed in the comparison of particular psychophysically determined functions. For comparable data, the functions relating (*a*) ΔI to I and (*b*) E to I should be identical in form.[2]

A further and equally specific consequence of this theory is that bimanual differential sensitivity may be *greater* than unimanual differential sensitivity. The experiment reported in the present paper was devised to ascertain the validity of this particular consequence.

Method, Apparatus and General Procedure.—The form of the function relating differential sensitivity ($= 1/\Delta W$) to the standard weight ($= W$) is known. It is accordingly deemed unnecessary to employ a large number of stimuli here to determine the relationship between differential sensitivity to weight and the magnitude of the standard. Seven values on the intensitive-continuum were selected: 100, 350, 500, 750, 1000, 1300 and 1600 grms. At each of these points, $1/\Delta W$ was measured by psychophysical procedure *unimanually* (each hand separately) and *bimanually* (both hands together) for three observers, the writers.[3] The method used was a special form of the method of limits [ascending direction; continuous change (21; 25)].

The apparatus has been described (13). An 'active' procedure was employed. In the bimanual presentation, for instance, two fiber cylinders were lifted to a height of 2.5 cm, and then lowered. This process was continued at a frequency of '30 per minute.' The rhythm was rendered essentially automatic by practice, and was governed by a metronome. The 'exposure-time' for each presentation was 2.5 sec (13). The adjusted weight was continuously increased until the observer reported a just

[1] The ideas underlying the theory discussed in relation to these experiments will not be altered at all should one see fit to define 'number of elements' as 'number of nerve fibers involved' in lieu of our present preference, the 'number of impulses per unit of time.' This point, and the reasons for our preference, will be discussed in a later paper.

[2] I is a symbol, in common use, employed to designate the stimulating intensity; E is a magnitude of the resulting effect.

[3] M.J.Z. is hereafter called Observer 1; J.E.S., Observer 2; and A.H.H., Observer 3.

noticeable difference in weight. Throughout the experiment, the average of ten observations constituted our measure of ΔW (in grams). These values were secured from each observer at each of the seven values of W for the left and right hands separately, as well as for both hands together. The bimanual experiment was temporally split into two phases. Bimanual data were collected before and after the unimanual experiments. In each experiment, the seven standard weights were presented in haphazard order. The stimulus-attitude was adopted by all observers (**7**; **8**).

Unimanual Differential Sensitivity.—Table I contains the

TABLE I

RESULTS FOR UNIMANUAL DISCRIMINATION

Each entry is an average of 10 measurements for an individual observer. W is the magnitude of the standard weight (in grams): ΔW_L is the difference between the standard and the adjusted weight for the left hand; ΔW_R, the difference between the standard and adjusted weight for the right hand. SD ($= \sigma_{\Delta W}$) is the root-mean-square variation of the distribution upon which ΔW is based.

	Observer 1		Observer 2		Observer 3	
W	$\Delta W_L \pm SD$	$\Delta W_R \pm SD$	$\Delta W_L \pm SD$	$\Delta W_R \pm SD$	$\Delta W_L \pm SD$	$\Delta W_R \pm SD$
100	55.41 ± 10.72	38.20 ± 3.45	33.89 ± 9.76	37.39 ± 6.86	34.97 ± 7.37	33.09 ± 2.99
350	67.74 ± 8.05	45.46 ± 6.78	44.39 ± 3.22	42.23 ± 4.37	36.05 ± 2.55	41.16 ± 4.36
500	70.04 ± 6.03	59.18 ± 8.02	51.07 ± 5.72	49.23 ± 8.11	55.95 ± 9.04	57.57 ± 10.86
750	75.85 ± 7.28	68.33 ± 6.83	59.18 ± 10.86	48.69 ± 10.03	71.55 ± 2.84	72.36 ± 8.40
1000	82.31 ± 7.78	87.16 ± 20.32	72.36 ± 25.82	55.95 ± 7.75	82.09 ± 5.17	81.24 ± 7.62
1300	92.00 ± 10.64	99.80 ± 6.32	72.90 ± 7.66	78.55 ± 17.72	106.52 ± 5.34	118.63 ± 20.74
1600	116.75 ± 13.86	125.35 ± 21.47	100.88 ± 20.14	98.99 ± 27.63	108.14 ± 13.45	127.82 ± 18.52

values necessary for a psychophysical characterization of the mechanism studied under the conditions of unimanual discrimination. The values in the column headed ΔW_L are for the left hand; those in the ΔW_R-column are for the right hand. Each entry for an individual observer is an average of 10 measurements. SD ($= \sigma_{\Delta W}$) is the root-mean-square deviation of the distribution upon which a mean ΔW is founded. Unimanual differential sensitivity to weight varies *inversely* as a function of W for all observers. As W is made to increase, the number of elements (= number of impulses per unit time) available for this discrimination presumably decreases also. These results are thus fully in harmony with the theory of differential sensitivity invoked to account for the results presented in the first paper of this series (**13**).

Bimanual Differential Sensitivity.—To determine the function connecting bimanual differential sensitivity and W, just noticeable increments in weight were measured for the same frequency, duration of exposure, and at the same levels of W

as were employed in the unimanual procedure. For the bimanual discrimination, however, the total amount of excitation per gross unit of time is unquestionably greater than it is for unimanual stimulation. The ΔW-values secured under these two sets of conditions need not agree. Relative to the magnitude of the unimanual measurements, there exist three mutually exclusive hypotheses which might be invoked to predict the magnitude of the bimanual determinations.

(1) Since the amount of excitation per unit time is perhaps doubled, it could be expected that ΔW would also increase (*cf.* the principle involved in Weber's law: $\Delta W = kW$). (2) However, the ΔW-values are not identical for the left and right hands; and in each bimanual presentation an observer might avail himself of his more sensitive 'hand.' In this event, the bimanual ΔW-values should coincide with those obtained unimanually for the more sensitive hand. (3) If the theory of differential sensitivity adopted to account for the unimanual results is fundamentally valid, then the ΔW-values for bimanual presentation should be definitely smaller than the lesser of the two unimanual values obtained at a given level of weight, W. The results secured in this experiment can be used to evaluate these three possibilities.

The results for bimanual presentation are shown in Table II, and are exhibited graphically along with those from Table I in Fig. 1. Bimanual and unimanual differential sensitivity

TABLE II

RESULTS FOR BIMANUAL DISCRIMINATION

Each entry is an average of 10 measurements for an individual observer. W is the magnitude of the standard weight (in grams): ΔW_1 is the difference between the standard and the adjusted weight for the experiment performed *before* the unimanual experiment; ΔW_2, the difference between the standard and the adjusted weight for the experiment performed *after* the unimanual experiments. SD ($= \sigma_{\Delta W}$) is the root-mean-square variation of the distribution upon which ΔW is based.

W	Observer 1		Observer 2		Observer 3	
	$\Delta W_1 \pm SD$	$\Delta W_2 \pm SD$	$\Delta W_1 \pm SD$	$\Delta W_2 \pm SD$	$\Delta W_1 \pm SD$	$\Delta W_2 \pm SD$
100	45.99 ± 7.30	21.79 ± 3.74	35.22 ± 12.79	23.95 ± 9.55	20.44 ± 4.78	20.45 ± 4.31
350	50.57 ± 7.88	41.98 ± 4.54	40.08 ± 14.89	34.86 ± 13.53	28.22 ± 5.51	34.20 ± 7.83
500	54.34 ± 6.03	37.12 ± 3.04	42.21 ± 8.15	38.39 ± 10.94	45.19 ± 6.74	42.50 ± 4.15
750	59.45 ± 6.66	58.64 ± 3.80	47.35 ± 18.29	41.16 ± 13.69	71.29 ± 8.76	62.14 ± 8.17
1000	62.68 ± 9.31	60.79 ± 5.25	63.49 ± 24.65	56.49 ± 16.84	72.09 ± 4.50	73.44 ± 6.70
1300	79.36 ± 11.16	83.93 ± 8.08	75.32 ± 22.42	69.13 ± 13.53	73.98 ± 6.13	100.61 ± 12.44
1600	105.72 ± 11.64	95.61 ± 14.86	105.99 ± 27.90	99.80 ± 22.15	107.14 ± 12.17	114.37 ± 6.17

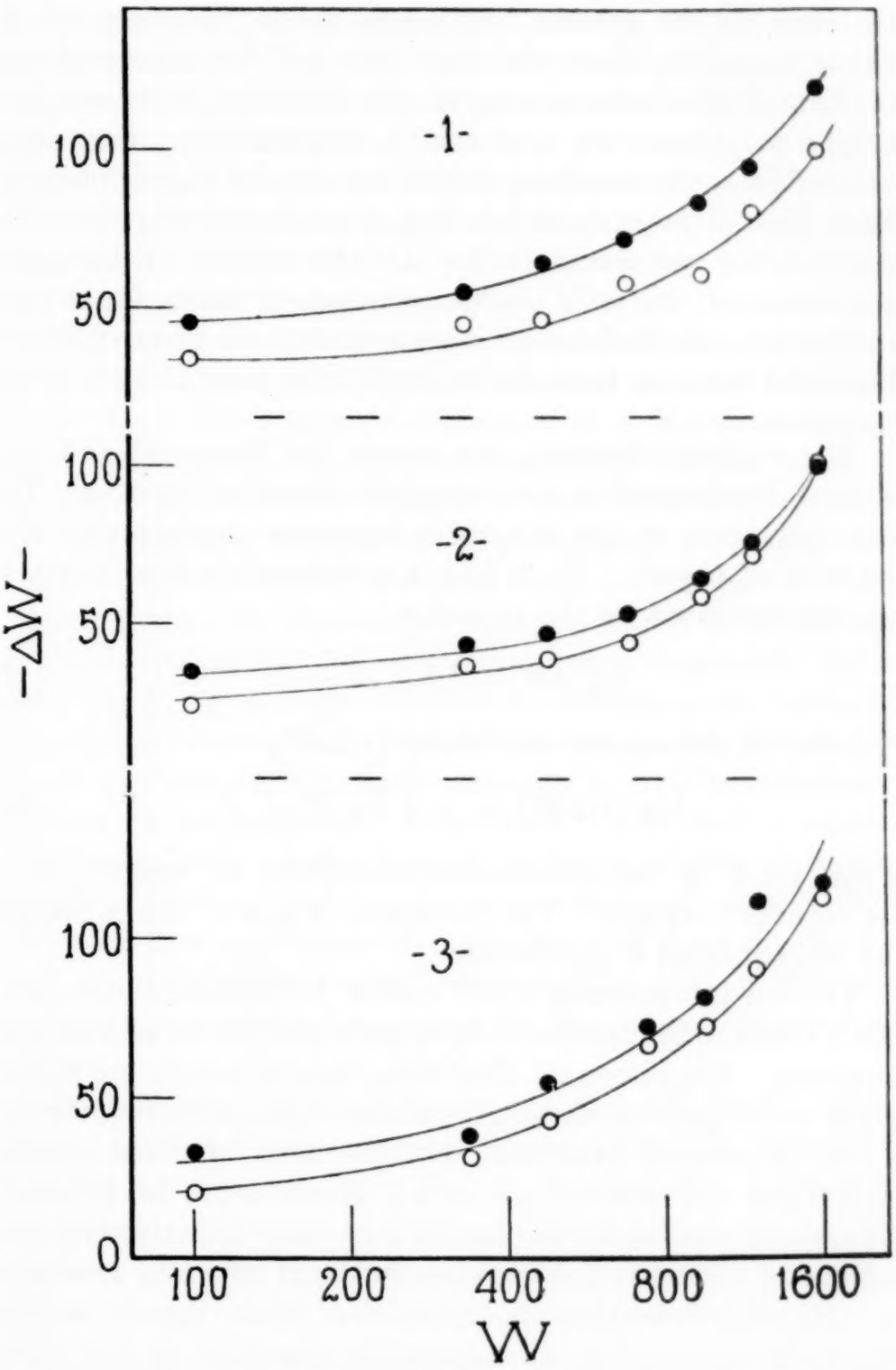

FIG. 1. Bimanual *vs.* unimanual differential sensitivity to weight. These functions are for Observers 1, 2 and 3, respectively. Each circle is an average of 20 measurements for an individual observer. The shaded circles are for unimanual discrimination; the open circles, for bimanual discrimination. Two hands are differentially more sensitive than one. W and ΔW are measured in grams. The abscissae are spaced logarithmically for visual convenience.

are seen to be specific and reproducible functions of W. These functions show the way that ΔW for bimanual and unimanual discrimination varies as a function of the standard weight for Observers 1, 2 and 3, respectively. For visual convenience, the abscissae-values are spaced logarithmically. Each plotted point is an average of 20 measurements. The open circles are averages for all the results of bimanual measurement; the solid circles, averages of results for the left and right hands (unimanual measurement) of a given observer. The solid lines are intended to depict the general form of the functions.

For a given observer, the curves for bimanual and unimanual discrimination are essentially identical in form. The first derivative of any one curve increases continuously as a function of log-W. To a first approximation the functions may be expressed by the equation

$$\log \Delta W = k \log W + c. \qquad [B]$$

In terms of differential sensitivity $(1/\Delta W)$,

$$\log (1/\Delta W) = - k \log W + c', \qquad [C]$$

where $1/\Delta W$ is the differential sensitivity to weight; W is the standard weight. The constants k and c' are arbitrary and the equation is provisional.

The law interrelating $1/\Delta W$ and W for bimanual presentation is taken to be identical in form with that for unimanual presentation. For bimanual discrimination, however, the values of ΔW are in general definitely *smaller* than are those obtained in the unimanual situation. On the basis of these results, possibilities (1) and (2) as stated above must be rejected. Differential sensitivity is observed to vary directly with the number of elements (= impulses per unit of time) available for the discrimination in question. This theory makes differential sensitivity a measurable capacity of the 'pre-efferent nervous system'—a capacity that is lawfully conditioned by peripheral events.

Discriminatory Precision.—Any one of the ΔW-values presented in Tables I and II is an average of 10 measurements.

To each ΔW is attached a standard deviation, a variation-index that is computed from the same 10 measurements. It has been common practice to regard variation as an inevitable and insurmountable difficulty. One way of treating variation-indices has been to associate them with such words as 'indeterminacy,' 'experimental error,' 'uncontrollable (!) variation,' and even 'freedom'; in effect, to relegate them almost completely to the limbo of ignorance.

There is another, an at least equally admissable, manner in which these operationally defined indices may be envisaged (3; 10; 13). They may be expressed as a function of some equally well controlled and experimentally defined variable, say, ΔW. If a uniform relation is then discovered to exist, the relation must be primarily a *biological invariant* (19). This follows from several considerations, not the least of which is the fact that the measurements basic to the mean and the standard deviation have themselves been organically determined (5; 6; 13; 14; 15). Evidence confirming the existence of a general invariant of this sort for the sensory discrimination of minimal differences in intensity is rapidly accumulating; and we are beginning to understand why such a relation can obtain, even in the face of such apparently unrelated stimuli as 'inches' and 'molar concentrations' (16). Moreover, to a first approximation, the force of the evidence has been to substantiate the presumption that differential sensitivity is lawfully determined by discriminatory precision (5; 10).[4]

The relations existing between $\sigma_{\Delta W}$ and ΔW for the results secured from the three subjects employed in this experiment are exhibited graphically in Fig. 2. Each circlet depends on an average of 10 measurements for a given observer. Graphs 1, 2, and 3 are for Observers 1, 2, and 3, respectively. Each ordinate has a standard deviation proportional to itself.

[4] As a matter of fact, for homogeneous data, $\sigma_{\Delta I}$ has been reported to be directly proportional to ΔI in vision (10; 18); in audition (2; 5; 22; 23); in kinesthesis (13); in cutaneous (9) and in deep pressure (20). The evidence is more complete for certain modalities than it is for others. For a presentation of these data, see (5). For functions based on measures which are of the order of variation-indices for taste and smell, see (15 and 26).

These relations can be described by a measure of central tendency. They are more completely described if the enclosing limits are known (**3**; **13**). Should the general relation be linear, as was suggested by Holway and Hurvich, the limits would then be parallel to the central tendency on a double-log grid (**5**; **10**). The data presented here are not sufficiently extensive to meet the requirements of a rigorous

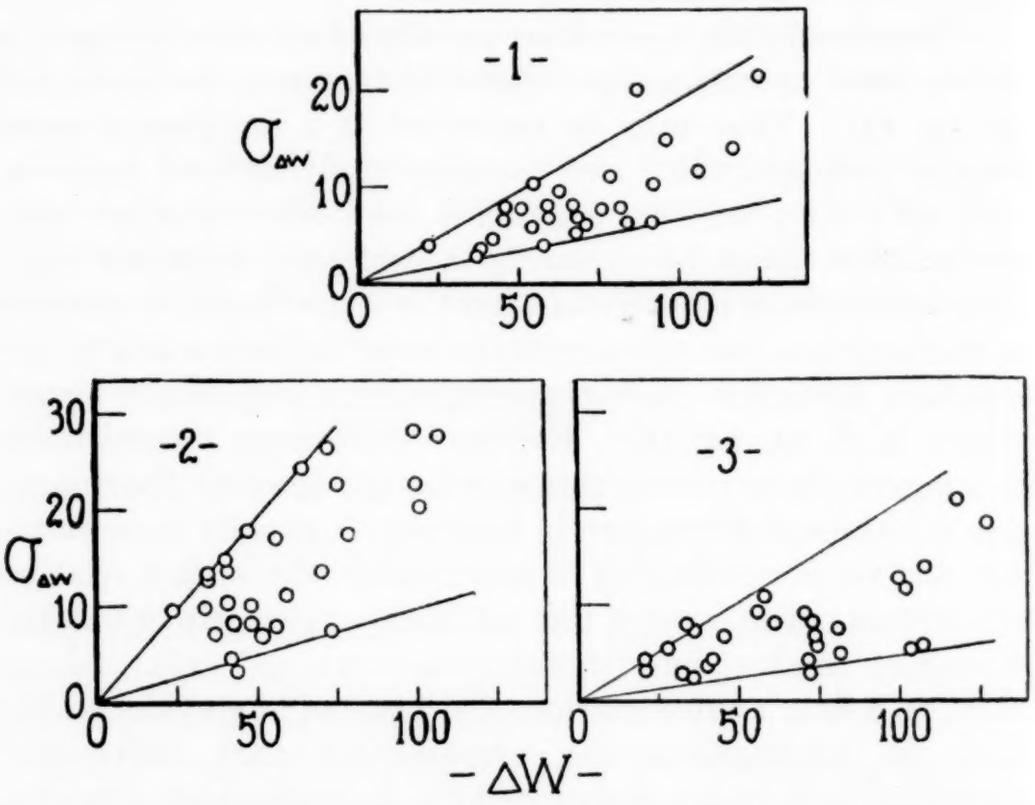

FIG. 2. Graphs showing the relationship between $\sigma_{\Delta W}$ (= root-mean-square variation) and ΔW for each of 3 observers: 1, 2 and 3. Each circlet is based on 10 measurements. See Tables I and II. Any ordinate-value has a standard deviation ($\sigma_{\sigma_{\Delta W}}$) which is *directly proportional* to the magnitude of the ordinate itself. The enclosing 'limits' are drawn on the assumption that $\sigma_{\Delta W} = k\Delta W$. See text.

test, and they are expressed arithmetically for convenience. The solid lines, the enclosing limits, were determined on the assumption of direct proportionality between $\sigma_{\Delta W}$ and ΔW. This hypothesis has also been assumed for previously obtained results, where the $\sigma_{\Delta W}$ versus ΔW relation was found to be independent of the mode of lifting the weights (**13**). More data are needed if the merits of this hypothesis for lifted weights are precisely to be determined. At the present time,

however, one fact seems clearly demonstrated. Precision of judgment ($1/\sigma_{\Delta W}$) varies directly with differential sensitivity ($1/\Delta W$). The magnitude of the one is governed by the magnitude of the other.

Summary.—The relationship of unimanual and bimanual differential sensitivity to weight has been determined at seven intensitive levels for three observers. A method of limits was used. In each instance, differential sensitivity ($1/\Delta W$) was found to vary inversely with W (in grams). For bimanual discrimination, however, differential sensitivity was found consistently to be greater than it was for unimanual discrimination. This finding can be accounted for in terms of a physiological theory: differential sensitivity varies directly with the number of elements (= number of impulses per unit of time) available for the discrimination of just noticeable differences in weight. The theory is thus a *supplement* to what has been called the volley theory of sensory intensity (1).

A contribution is also made in regard to the relation between discriminatory precision ($= 1/\sigma_{\Delta W}$) and differential sensitivity ($= 1/\Delta W$). Discriminatory precision and differential sensitivity are found to vary directly. The suggestion is made that this relation may be an *invariant* property of the human organism.

(Manuscript received January 27, 1937)

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THE STRENGTH AND DIRECTION OF ASSOCIATIONS FORMED IN THE LEARNING OF NONSENSE SYLLABLES*

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I. Problem

The concept of the formation of remote associations during learning was first formulated by Ebbinghaus (3). This concept, briefly stated, is that, in learning a series of items, associations are formed not only between adjacent items but also between each item and every other item in the series. Such remote associations have been diagrammed by Hull in a recent article (7). This diagram is reproduced below, the straight broken arrows representing immediate associations, and the curved solid arrows representing remote associations.

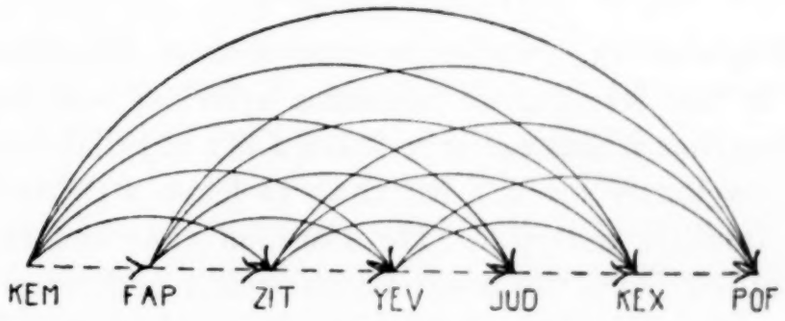

Fig. 1

Two questions arise in studying the diagram. First of all, is an immediate direct association set up between the last syllable of one repetition of the series and the first syllable of the next repetition, especially when the interval between the two repetitions is no greater than the interval between any two successive syllables? Secondly, since remote associations are supposed to extend forward from each syllable to every syllable which follows, are remote associations set up between

*The authors wish to acknowledge the assistance of Professor W. T. Heron under whose direction this study was carried out.

syllables separated by the interval between repetitions? An example of such an association would be one going from POF to ZIT, since ZIT in the second repetition of the series comes after POF, which is the last syllable of the first repetition. Associations of this nature could be called backward associations, since, when the series is considered as a unit, they are between a given syllable and one preceding it. If backward associations are found, a further question arises as to whether they are remote forward associations formed in the manner described above, or are associations formed in a backward direction between a given syllable and one which precedes it, within a single repetition of the series.

The literature on the formation of associations during learning does not furnish us with a clear-cut answer to any of these questions. Nowhere is the problem of associations formed across the interval between repetitions considered.[1] In the case of backward associations, not only is their nature uncertain, but conclusive evidence for their existence is lacking.

II. Literature

Ebbinghaus' (3) conclusion that remote associations are formed in the learning of nonsense syllables was based on his finding that it was easier to learn a list of syllables derived from a previously learned list than to learn a control list of equally familiar material. He assumed that the saving in time resulted from the associations which had been formed between non-adjacent syllables in the original learning list. Since he found progressively smaller percentages of saving for lists made up of syllables of increasing degrees of separation, he concluded that the strength of remote forward associations decreased with an increasing degree of remoteness from a given syllable.

[1] Directly prior to submitting this article for publication we received a copy of McGeoch's article in the April, 1936, issue of the *Amer. J. Psychol.* (11). McGeoch considers the possibility that when successive presentations follow each other with a short interval between, the list may be learned as a circular series. Although in a number of ways the studies are not comparable, discrepancies and similarities in results and interpretations have been pointed out in several footnotes.

The existence of remote forward associations was denied in 1926 by Cason (**1**) who, using lists of words derived from a previously learned prose passage, found no saving over a control list. He concluded that forward associations between adjacent items are the only associations that are formed. It is probable that his failure to obtain saving was due to the fact that he used prose material in which individual words are such inseparable parts of meaningful word groups that no remote associations between separate words could be formed.

Hall (**5**), attempting to reconcile the conflicting results of Ebbinghaus and Cason, found savings when relearning took place after a week but none when it took place immediately.

Other evidence concerning the presence of remote forward associations has come from the analysis of 'place-skipping' errors made in the learning of a series of discrete items. Both Lumley (**8**, **9**, **10**) and Mitchell (**12**, **13**) find that in learning such a series there is a definite tendency to skip several items when attempting to anticipate the correct response. These anticipatory place-skipping errors are assumed to result from the presence of remote forward associations. Moreover, they found that the largest number of errors consisted in skipping one item and that the frequency of the errors for each degree of anticipation decreased with increasing distance from the stimulus syllable.

Ebbinghaus (**3**) found evidence which led him to conclude that backward associations, also, were formed in learning a list of syllables. The presence of backward associations was indicated by the savings obtained in learning new lists derived by completely reversing the order of the original list or by reversing items of alternate pairs. As in the case of remote forward associations, he found a decreasing strength with increasing degrees of remoteness. The only study which confirms Ebbinghaus' finding is that of Garrett and Hartman (**4**), who found a sixty percent saving for a reversed order list. Some suggestion of evidence in favor of backward association is found in Cason's (**2**) finding of a fractional saving in the relearning of a reversed order series. This saving, however, he attributes to fluctuation in attention in

learning the original list, and not to the formation of backward associations when the list was learned in the first place.

Lumley and Mitchell, in the studies referred to above, are agreed that anticipatory errors in a backward direction are infrequent. This finding cannot, however, be considered disproof of the existence of backward associations, since the subject is not likely to give as an anticipatory response those syllables which he has just seen exposed for the preceding positions in the series.

III. Procedure

Subjects.—The subjects for our experiment were twenty-four university undergraduate students.

Method of Learning Nonsense Syllables.—The learning series consisted of eight nonsense syllables which were equal in associative frequency.[2] Each syllable was exposed on a memory drum for a period of approximately 2.5 seconds. Between repetitions a blank space appeared for an interval of 6 seconds. The anticipatory recall technique was used, the subject correcting himself silently. The first syllable was neither pronounced nor anticipated. The criterion of learning was three perfect repetitions in succession, after which the subject was tested for associations by the method described below.

Method of Testing for Associations Formed During Learning.—The syllables were arranged in random order, each syllable occurring in the list three times. The experimenter called aloud each syllable to the subject, asking him to respond with the first syllable in the series 'that popped into his head.' We adopted this procedure on the assumption that the presentation of a stimulus syllable should elicit in response a syllable with which an association had been formed. The frequency of such a response would be expected to vary with the strength of the association.[3] The results obtained from five of the subjects were rejected, since they gave a majority of stereotyped responses (continued repetition of the same response to different syllables), of blockings, or of syllables not in the original series. Hence the data described below are based on nineteen subjects.

IV. Results

The frequency with which each syllable was given as a response to every other syllable in the series was first com-

[2] These syllables were chosen from a list published by Hull (6) in his study on the effect of caffein on rote learning.

[3] We find that McGeoch's study also employs this technique of testing for associations. Previous to the receipt of his article, the only approximation to our method we could discover in the literature was a study made by Wohlgemuth (15) in 1913. The latter's instructions to his subjects to respond with an item in the series directly preceding or succeeding the stimulus item limited the associations that could be tested for to the immediate forward or backward ones.

puted. Table 1 summarizes these computations. The order of syllables on the axes is the same as the order in which they were presented during learning, the column labeled 'misc.' referring to miscellaneous responses, *i.e.*, response syllables that were not from the learning series.

TABLE 1

FREQUENCY TABLE OF RESPONSES OF EACH SYLLABLE TO EVERY OTHER SYLLABLE

Stimulus Syllables	Response Syllables: KEX	YUT	ZAL	NIJ	YIK	MIB	NUV	YEV	Misc.
KEX	1	31	2	0	2	4	8	5	3
YUT	1	0	33	8	3	1	3	2	5
ZAL	2	13	0	20	5	8	4	2	3
NIJ	1	1	5	0	25	15	6	1	3
YIK	0	0	9	1	0	33	9	2	2
MIB	1	6	5	6	8	1	15	5	7
NUV	0	5	3	2	3	5	2	38	1
YEV	11	12	6	3	3	4	12	3	4

Thus as a response to KEX, KEX itself was given once, YUT thirty-one times, ZAL twice, NIJ never given, YIK twice, MIB four times, NUV eight times, YEV five times, and miscellaneous responses three times. The blocked-out diagonal column represents the frequency of immediate direct associations.[4] Since the series is here considered as a discrete unit, all responses to the right of this column indicate, therefore, remote forward associations, those to the left of this column, backward associations.

Of the total 453 responses,[5] 195 or 43 percent were immediate direct associations, 128 responses or 28 percent were back-

[4] An examination of this diagonal column reveals no regular variations in the strength of immediate associations with position in the series. Hull's theoretical deduction (7, 502), that the immediate excitatory tendency between the last two syllables must be appreciably weaker than between the first two syllables or even between the third and fourth syllables, fails, therefore, to be confirmed experimentally.

[5] Since each of the 8 syllables was presented three times, the total number of responses for the 19 subjects would be 456. In the case of 3 subjects, however, the third repetition of a stimulus syllable was accidentally omitted from the record blank.

ward associations, 95 or 21 percent were remote forward associations, the remaining 35 responses or 8 percent being either repetitions of the stimulus word or miscellaneous responses.

Although the series is learned so that the subjects must recite the syllables in direct order, less than half of the responses were immediate direct ones.[6] From the above assumption that an association exists between a syllable and one which is immediately evoked in response to this syllable, the remaining 49 percent of responses indicate the formation of *remote* forward or backward associations during the original learning.

An examination of Table 1 gives an unequivocal answer to our first question: namely, an association *is* set up between the last syllable of one repetition of the series and the first syllable of the next.[7] The crucial evidence for this association is that out of the seventeen responses of KEX, eleven of these were given to YEV, while the remaining seven are scattered at random among the remaining seven syllables. It can further be shown that the association between the last syllable of one repetition and the first of the next is as strong as any immediate direct association in the series. By adding the frequencies of KEX and YUT as responses to YEV, we obtain a total frequency of twenty-three, a figure only slightly less than the average frequency of the immediate direct responses, which is twenty-eight. (This figure was obtained by adding the frequencies in the blocked-out squares and dividing by seven.) Our justification for adding the frequency of YUT to that of KEX to obtain the total frequency of giving the initial syllable of the series as a response to YEV, is that the subjects who responded with YUT, upon being questioned, had never noticed what the actual first syllable

[6] McGeoch found approximately the same percentage of backward associations. The frequency of his immediate direct and remote forward associations was somewhat less than ours. For instance, in his Experiment I (when the list is treated as a linear series) 36.19 percent of the associations were in a backward direction, 21.27 percent were immediate direct associations and 25.5 percent were remote forward ones.

[7] It is interesting to note McGeoch's finding in one experiment of his study that "a few associations from the last word of the list to the cue word have been obtained."

in the series was. This, we think, was a natural consequence of the fact that KEX was neither pronounced nor anticipated during the learning process. For these subjects KEX merely served as a cue that the series was about to begin. Therefore, we believe it is legitimate to consider the response of YUT to YEV as a direct connection between the last syllable of one repetition and the first of the next. Obviously these responses of KEX and YUT may be considered sixth or fifth remote backward associations respectively. Nevertheless the most reasonable interpretation is that this association is an immediate direct one. The evidence leading us to draw this conclusion will be discussed below.

Our next step was to investigate the strength and direction of the remaining associations. It is apparent from Table 1 that forward associations show a general tendency to decrease from left to right, whereas backward associations show a similar tendency from right to left. To obtain the strength of these associations we first added the frequencies in the squares making up the blocked-out diagonal. This gave us the total frequency of immediate direct responses, considering as direct responses only those which may be diagrammed in a single repetition of the series. (On this principle, the association between YEV and KEX would be called a sixth backward remote association rather than an immediate direct one.) Similarly, to obtain the frequency of first forward remote associations, we added the frequency in each square immediately to the right of the blocked-out diagonal. In a like manner we determined the total frequency of the other remote forward associations. To obtain the strength of our immediate backward associations, we added the frequencies in the squares second to the left of the blocked-out diagonal (the squares immediately to the left of the blocked-out diagonal represent repetitions of the stimulus syllable); for the first backward remote association, we added the frequencies in the squares third to the left of the blocked-out diagonal, etc. The results of these tabulations are given in Table 2.

Since the possibilities for the different degrees of associations were unequal, we have corrected the frequencies for

TABLE 2

FREQUENCY TABLE SHOWING STRENGTH OF FORWARD AND BACKWARD ASSOCIATIONS WITHIN A SINGLE REPETITION OF THE SERIES

Forward Associations	Frequency		Backward Associations	Frequency	
	Uncorr.	Corr.		Uncorr.	Corr.
Immediate Direct.....	195	195	6th Backward Remote.....	11	77
1st Forward Remote.....	44	51	5th Backward Remote.....	12	42
2d Forward Remote.....	19	27	4th Backward Remote.....	12	28
3d Forward Remote.....	8	14	3d Backward Remote.....	12	21
4th Forward Remote.....	9	21	2d Backward Remote.....	11	15
5th Forward Remote.....	10	35	1st Backward Remote.....	25	29
6th Forward Remote.....	5	35	Immediate Backward.....	45	45

that factor. To illustrate, there were seven syllables which could have immediate direct associations, and only three which could have fourth forward remote ones. To equate the two, we multiplied the frequency for the fourth forward remote association by seven-thirds. Likewise we multiplied the frequency of the fifth forward remote associations by seven-halves and so on.

The 7 percent superiority (28 percent of the total responses being backward associations and 21 percent being remote forward) in frequency of the backward associations over the remote forward ones has already been noted. The surprising strength of these backward associations may also be seen from Table 2 which shows that the strongest uncorrected association after the immediate direct is the immediate backward, although the difference between it and the first forward remote is slight. The first backward remote association is likewise stronger than the second forward remote.

The corrected column for forward associations in Table 2 shows a gradual decrease in strength of association with increasing remoteness until the fourth degree of remoteness is reached. Up to this point, then, our results on the strength of forward remote associations are in substantial agreement with the results of Ebbinghaus, Mitchell, Lumley, etc., which indicate an inverse relationship between strength of association and degree of remoteness. After the third remote association, however, there is a gradual rise in frequency

which continues through the last degree of remoteness.[8] It is obvious that this result directly contradicts the previous finding of an inverse relationship between strength of associations and degree of remoteness in a forward direction.

We believe this increase in strength of the more remote forward associations is due to the fact that these associations correspond to strong associations formed in a backward direction across the interval between repetitions. To illustrate, the apparent great strength of the sixth remote forward association, that is, giving YEV to KEX, results from the fact that YEV is also the immediate association, in the backward direction, to KEX, when the series is repeated as indicated below:

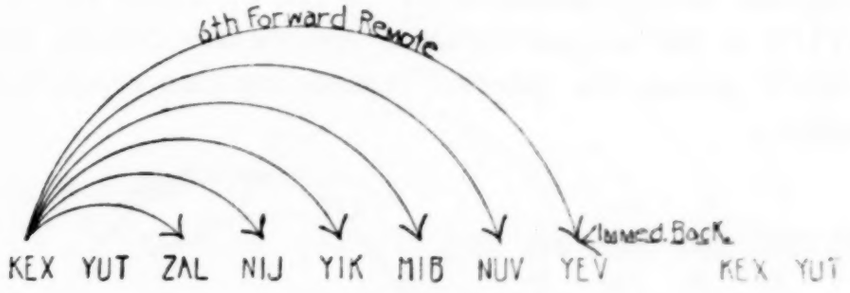

FIG 2.

That this explanation is the correct one is supported by the great strength of the immediate backward association (frequency of 45 as recorded in Table 2) as compared to all remote forward associations beyond the first.

A further examination of the backward associations in Table 2 reveals a tendency parallel to that found for the

[8] McGeoch concluded that there was no relation between strength of association and degree of remoteness, and that evidence to substantiate Ebbinghaus' contention was lacking. When, however, we corrected McGeoch's total frequencies for the unequal opportunities of occurring which the different degrees of remoteness had, the strength of associations decreased consistently with increasing remoteness up to the fourth degree of remoteness. As in our study, this was followed by a gradual increase in strength of association from the fourth to the maximum degree of remoteness. An indication that McGeoch noticed this rise in frequency is found in his statement that "the only variation which appears with any consistency is that in the direction of an increased number of associations at the greatest or next to the greatest possible degree of remoteness from each of the first four positions of the stimulus word." He concluded, however, that "it was neither sufficiently large nor sufficiently regular to merit detailed examination."

remote forward associations. That is to say, the strength of the backward associations decreases from the immediate to the fourth backward, thereafter increasing through the sixth backward remote association.[9] The frequency of the latter is actually greater than that for the immediate backward association. The paradoxical strengths of these more remote backward associations can be explained as were the paradoxical strengths for the more remote forward associations; *i.e.*, the response syllables for the more remote backward associations correspond to those of the more immediate forward remote associations which span the interval between repetitions of the series. For instance, the strength of the fourth backward remote association, that is (as shown in the diagram below) giving YUT to NUV, is due to the fact that YUT is the second forward remote association formed from NUV across the interval separating two repetitions of the series.

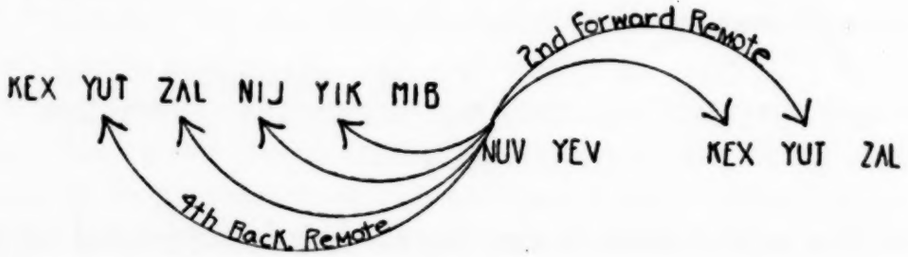

FIG. 3

A different method of analyzing the data has confirmed the above results. In this second approach we considered all associations to be forward associations, treating two repetitions of the series as a single series of twice the length of the original.

In Fig. 4 NIJ is the fifth forward remote association from MIB. In deriving Table 2, on the other hand, it was considered a first backward remote association, since we were then naming associations as either backward or forward depending on the position of the syllable in relation to the stimulus syllable, within a single repetition of the series.

[9] This increase in frequency following the initial decrease is also found for the extreme degrees of remoteness when McGeoch's frequencies for backward associations are corrected in the manner described above.

Furthermore, by this method, wherein forward remote associations are considered to span the interval between repetitions, MIB now has six forward remote associations, while just one was possible by our former method of analysis.

The resulting frequencies obtained by this method for different degrees of remoteness are found in Table 3. For instance, the total frequency for the fourth forward remote association was found by adding the frequencies with which MIB was given to KEX, NUV to YUT, YEV to ZAL, KEX to NIJ, YUT to YIK, ZAL to MIB, NIJ to NUV, YIK to YEV. This gave a total frequency of twenty for the fourth forward remote association. This process was repeated for

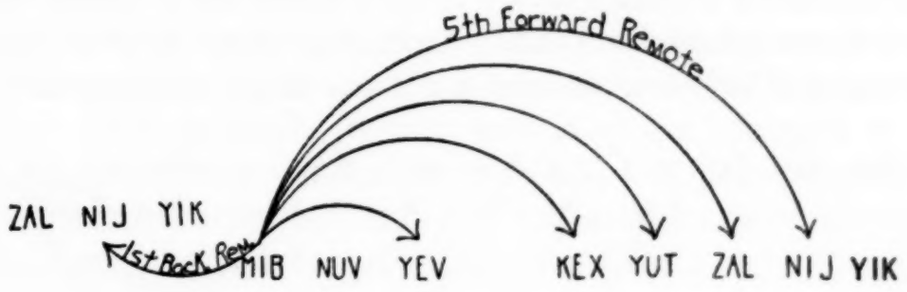

FIG. 4

the other degrees of forward remote association. The results are tabulated below.

The data of Table 3 lead to conclusions identical with those reached from the results recorded in Table 2. The strength of forward associations decreases with increasing

TABLE 3

FREQUENCY TABLE SHOWING STRENGTH OF ALL FORWARD AND THE BACKWARD ASSOCIATIONS TO WHICH THEY CORRESPOND, INCLUDING THOSE FORMED ACROSS THE INTERVAL BETWEEN REPETITIONS

Forward Associations	Frequency	Backward Associations
Immediate Direct	206	6th Backward Remote
1st Forward Remote	56	5th Backward Remote
2d Forward Remote	31	4th Backward Remote
3d Forward Remote	20	3d Backward Remote
4th Forward Remote	20	2d Backward Remote
5th Forward Remote	35	1st Backward Remote
6th Forward Remote	50	Immediate Backward

remoteness through the third forward remote association. There is no difference between the strength of the third and fourth degrees of remoteness. From the fourth forward remote association on, there is an *increase* in the strength of the forward associations with *increasing* degrees of remoteness.

Since forward remote associations should presumably *decrease* with *increasing* degrees of remoteness, it is necessary again to explain the paradoxical increase in strength of the more remote forward associations. What this explanation may be is revealed by computing the frequencies for backward associations in the same way as the frequencies for the forward associations were computed. An illustration for a single syllable is diagrammed below, where the possible backward associations from ZAL, including those formed across the interval between repetitions of the series are shown.

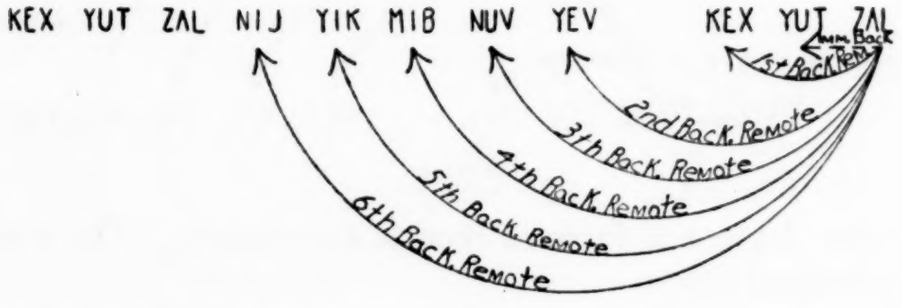

FIG. 5

When the associations are classified in this manner, the response of YEV to ZAL becomes a second backward remote association where it was formerly classified as a fourth forward remote. Similarly, the immediate backward association corresponds to the sixth forward remote association, the first backward remote to the fifth forward remote, the third backward remote to the third forward remote, the fourth backward remote to the second forward remote, the fifth backward remote to the first forward remote, and the sixth backward remote to the immediate direct. The frequency for each degree of forward association and the degree of backward association to which it corresponds, has already been given in Table 3.

It is clear then that what we have termed the paradoxical increase for the fifth and sixth degrees of remote forward association is a result of the great strength of the immediate backward and first backward remote associations. Likewise, the paradoxical strength of the fifth and sixth backward remote associations is due to the great strength of the immediate direct and first forward remote associations to which the backward ones correspond. In other words, the great frequency of the responses for the fifth and sixth degrees of forward remoteness is not due to the inherent strength of these associations, but rather to the fact that the syllables which occupy positions of the fifth and sixth degrees of forward remoteness are identical with the syllables which are the immediate backward and first backward remote associations to the stimulus syllable. As Fig. 2 shows, the frequency of giving YEV to KEX, results not from the strength of the sixth forward remote association (which *a priori* should be weak) but from the fact that YEV is also the response for an immediate backward association from KEX.

V. Conclusions and Summary

The results obtained with our technique have not only confirmed evidence found by other methods that remote forward associations are formed in the learning of a series of nonsense syllables, but have also established the fact that such associations are formed across the interval separating successive repetitions of the series. The evidence clearly indicates that backward associations, also, are formed during the learning of such a series. As in the case of forward associations, the associations in a backward direction are formed between non-adjacent as well as adjacent syllables, including syllables which are separated by the interval between repetitions of the series.

This finding of the existence of backward associations in the learning of nonsense syllables gains support from the experimental investigations on backward conditioning. Both Switzer (**14**) and Wolfle (**16**) find conditioning to be possible when the unconditioned stimulus precedes the conditioned stimulus. Yarbrough (**17**) found that making associations in

the backward direction was very little, if any, more difficult than in the forward direction when the terms are presented in immediate succession.

The presence of immediate and remote associations both in the forward and backward directions, including those formed across the interval between repetitions of the learning series, must be taken into consideration by any system which attempts to explain the phenomena of learning. For example, Theorem I in Hull's miniature theoretical system (7) that the number of remote excitatory tendencies spanning a given syllable will be $(n - 1)(N - n)$ (where N is the number of syllables and n is the ordinal number of a particular syllable) no longer holds. All theorems dependent upon Theorem I, such as the one predicting the total inhibition of delay at a given syllable, are likewise affected. The experimental findings of this investigation appear, then, to call for a change in the postulates and consequently a revision of the theorems which are logically derived from these postulates.

To summarize our results:

1. Associations are formed between syllables across the interval between repetitions of the series. In our own experiment, the bond between the last syllable of one repetition and the first syllable of the next has the strength of an immediate direct association.

2. During the learning process, backward associations are set up, whose combined strength is greater than the combined strength of remote forward associations.

3. Backward associations cannot be considered forward remote associations which span the interval between series, since their strength is much greater than the strength the forward associations, to which they correspond, would be expected to have.

(Manuscript received July 15, 1936)

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A FURTHER STUDY OF THE EFFECT OF NON-INFORMATIVE SHOCK UPON LEARNING

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Some time ago the writer reported data which he interpreted as indicating that electric shocks administered as penalties for errors made during the learning of a stylus maze may under certain conditions facilitate learning, even when such shocks are introduced in the learning situation in such a way that they cannot function as signals for error or as specific guiding cues (**4**). A possible explanation of the apparent discrepancies between these results on the one hand and those of Tolman, Hall and Bretnall (**9**), Muenzinger (**8**), and Gilbert and Crafts (**3**) on the other, was suggested.

Since the completion of these experiments Bunch (**1**) also has reported maze data in support of the view that shocks for errors may have upon learning a facilitating effect over and above that which might be explained in terms of their signal or informative functions. Using a stylus maze, Bunch had a group of subjects learn under control conditions, *i.e.*, with no shocks associated with errors; a second group learned with shocks for errors, and a third group learned with verbal cue instead of shock at the end of each blind alley. The results are summarized in the following table, which presents the differences in mean trial, error and time scores and the critical ratios. In each case the group named first in the first column has the greater mean.

BUNCH'S MAZE DATA

Groups Compared	Trials		Time		Errors	
	Diff.	Diff./σ Diff.	Diff.	Diff./σ Diff.	Diff.	Diff./σ Diff.
Control—Shock	26.90	5.60	433.14	3.17	232.64	4.43
Control—Verbal Cue	16.01	3.38	239.23	1.57	27.01	.38
Verbal Cue—Shock	10.89	3.65	194.01	1.62	206.63	3.71

From these data Bunch concludes: "Evidently the beneficial effect of electric shocks in terms of trials and time is partly a function of the informative aspect involved in thus distinguishing errors from correct acts, while in terms of error scores the effect is almost entirely a function of the aspect involved other than the informative one, namely, punishment."

As further evidence that the effect of shocks is only partly a function of their informative value, Bunch cites the fact that in her experiments in which shocks were given only during two or three trials, the efficiency of learning was greater during the post-shock trials than was the case at the same stages in learning when electric shocks were not used at all; and the effect upon learning was as great from the use of four trials with shocks as when eight or twelve were used. "If the effect of electric shocks were mainly a function of their informative value, one would expect the presence of the additional sensory cue to continue to have some informative value, and hence facilitate learning as long as the subject experiences difficulty in distinguishing incorrect from correct segments, in other words, until the problem is learned" (*op. cit.*).

While the results of Bunch's experiment seem to lend support to our view that shocks may have a facilitating effect upon learning apart from their signal function, some of her data are at variance with our earlier findings (Gilbert and Crafts (**3**)). To be specific, Bunch found that her group learning with shocks for errors made fewer errors than her group learning with verbal cues for errors, while our data indicated that there were no significant differences according to any criterion between groups learning with shock for error and auditory cue for error respectively. The small differences as regards trials and errors actually favored the auditory signal group. Since the data on record are not wholly unambiguous, it would seem desirable to supplement Bunch's data with the results of experiments in which shocks are introduced in such a way that they cannot serve as signals or specific guiding cues, as was done in our experiment mentioned in the first paragraph of this article.

Although in our 'non-informative shock' experiment in which a blind stylus maze was employed fairly reliable differences between group means were obtained, it was decided to perform a similar experiment using a modified punchboard maze, in the hope of reducing variability within the distributions of scores and of obtaining thereby more reliable measures of central tendency. There is no retracing in a punchboard maze, and other factors which enter into the blind stylus maze situation in such a way as to increase variability, are absent in the punchboard situation—a situation in which the subject does not perform blindly. While our hopes were not fully realized, our findings were not in any way at variance with those of our stylus maze investigations, and they would seem to lend further support to the conclusion that electric shocks given for errors made in learning have a facilitating effect which is not wholly attributable to their informative value.

Subjects, Apparatus and Method

Subjects.—The subjects were one hundred and five undergraduate students at Washington Square College, New York University. Fifty three of these subjects comprised a control group which learned the maze under ordinary conditions, the remaining fifty two constituting the experimental group learning with the 'non-informative' shock for errors. The two groups, which were equated by random selection, were similar as regards chronological age, class of origin, etc., and they were found to perform upon the same level upon a preliminary maze pattern which was learned by both groups under the same conditions. The subjects were, as drafted from the student body, placed alternately in the two groups.

Apparatus.—The apparatus used was suggested by the punchboard maze employed by Tolman and his associates [9] and by Muenzinger,[8] but the details of construction were different in many respects. Instead of using the large three foot square board having thirty pairs of holes for the insertion of the stylus tip, a smaller board of plywood a little more than one foot square was used, with fifteen pairs of stove bolts passed through holes drilled in the board. The board was faced with thick white cardboard, and only the ¼" round heads of the bolts appeared on this facing, the electrical connections being made on the under side. The pairs of heads were numbered in black on the white facing to indicate to the subject the order in which they were to be tried. All the 'right choice' bolts were connected by wires placed beneath the board with a binding post for the lead taken from the recording apparatus.

The stylus used was the same as that employed in our earlier studies, and described in detail elsewhere (5). In brief, it is a stylus having a tip which is insulated from the handle and connected by a flexible wire with the recording apparatus (or which may constitute a part of the primary circuit of an inductorium in experiments in which shocks are given automatically). Brass rings are inlaid in the bakelite handle of the stylus, to which leads are taken from the secondary terminals of an induction coil,

half the rings being connected to one terminal, the remaining rings to the other. Thus shocks may be administered without the use of electrodes attached to parts of the body other than the stylus hand.

In the experiment here reported connections were made in such a way that contact of the stylus tip with one member of each pair of bolt heads would operate an electric counter, thus recording right choices automatically. The sharp click of the counter was used as a signal to inform the subject when he had made a correct choice. The shock was given by operating a telegraph key placed in the primary circuit of a Porter inductorium.

The maze was placed flat on the table in front of the subject. All pieces of apparatus used in the experiment with the exception of the maze and the stylus were screened from the subject's view. In addition to the fifteen unit maze, a small six unit pattern was provided for preliminary practice.

Procedure.—The procedure in general was as follows. The two groups, experimental and control, learned the preliminary six unit pattern to the satisfaction of a criterion of two of three successive trials without error. The subjects of both groups then learned the fifteen unit pattern to the satisfaction of the same criterion. The conditions were the same for the two groups while learning the preliminary pattern, but the experimental group learned the fifteen unit pattern with non-informative shock for errors. A perfect or errorless run constitutes a trip from pair No. 1 to the end of the series with no selections of contact heads which fail to give clicks. Subjects were instructed to refrain from correcting wrong choices, and they were watched to insure that these instructions were carried out.

The purpose of the small practice pattern was to familiarize the subject with his part in the experiment, and to reduce variability within the distributions of scores recorded in the main experiment. Furthermore the preliminary scores were used as rough measures of our success in equating the groups.

As to the details of the procedure:

(1) The measures recorded were (*a*) number of trials required for learning; (*b*) number of errors made during the learning; (*c*) time required for learning. The time required for each trial was determined through the use of a stop-watch.

(2) The criterion of learning was as has already been said, to make two of three successive trips through the series without error.

(3) The 'non-informative' shock, given subjects of the experimental group, was administered in much the same way as in our similar experiment with the stylus maze. Subjects were told before starting to learn under experimental conditions that they would receive shocks as penalties for making errors, *but that they would not receive a shock for each error made*, and that no shock would be given at the time of, or immediately following the commission of an error. They were told that the number of shocks would be roughly proportional to the number of errors made, but emphasis was placed upon the fact that shocks would not be associated with specific errors. Shocks were to enter into the situation now and again as long as the subject continued to make errors. During the earlier stages of learning one shock was given for every five errors, but later when only one, two or three errors were made on any one trial, a shock was given for every two or three errors. Care was taken not to administer shocks just after the making of an error, and many of the shocks were given after the completion of trials.

Since there are widespread individual differences with respect to sensitivity to electrical stimulation, the intensity of the shock stimulus to be used with any given subject was determined by testing the subject before the start of his work with the experimental pattern (but after the learning of the preliminary pattern). The subject

was given the stylus, and the inductorium was adjusted with very little overlapping of primary and secondary coils. The secondary was then moved so as to increase the amount of overlap gradually, the primary circuit being closed for a brief period for each position of the secondary, until the subject reported 'too much,' or jumped excessively, or dropped the stylus. The overlap was then decreased slightly, and learning began with an amount of shock not too painful, but definitely annoying to the majority of subjects. As adaptation occurred during the course of the experiment the strength of the shock was increased, so that the subject usually jumped a little when the shock was given, or in other ways gave evidence that the shock was not too mild.

(4) The practice may be regarded as massed, as the rest periods between trials were very short—usually less than a minute.

(5) Instructions were given verbally. The use of the practice pattern insured familiarity with the procedure by the time the subject was ready to start learning the fifteen unit pattern. Subjects were told that contact of the stylus tip with one member of each pair of heads would produce a click, while one member of each pair would be found to be 'dead'; that his task would be to try the pairs in the order numbered, to discover the heads giving clicks. Choices producing the clicking sounds were to be regarded as correct choices, and trip after trip was to be made through the series until two of three consecutive trips were errorless. It was made clear to the subject that in cases where the 'dead' member of a pair was selected, he was not to correct his selection, but to go directly to the next pair.

After having learned the fifteen unit pattern, each subject of the experimental group was asked the following questions:

1. Was the shock annoying?
2. Do you think you would have done better without the shock?
3. Did you try to avoid making errors so as to avoid getting shocks?

Results

The mean trial, error and time scores for the two groups appear in Table I, as do also the standard deviations of the several distributions, the differences between the corresponding means, and the critical ratios.

TABLE I

Criterion	Experimental		Control		Difference	$\frac{\text{Diff.}}{\sigma \text{ Diff.}}$
	Mean	σ	Mean	σ		
Trials	13.48	7.12	15.75	6.32	2.27	1.72
Errors	47.82	26.12	57.66	24.00	9.84	1.99
Time in Seconds	339.76	158.23	357.67	140.30	17.91	.61

As may be seen by reference to Table I, the experimental group is superior to the control group according to all three criteria—trials, errors and time, although the differences are not highly reliable as judged by the indices obtained through

the use of the conventional methods, which are based upon the assumption of normal distributions of data. Examination of Table II will reveal the fact that the trial scores are so distributed that reliability may be estimated in terms of sigma values and the usual critical ratio. The difference between mean trial scores is 2.27, bearing to its standard error a ratio of 1.72, usually interpreted as indicating that the chances of there being a true difference greater than zero and in the direction indicated are 96 in 100.

TABLE II

FREQUENCY DISTRIBUTIONS OF TRIAL AND ERROR SCORES

Trials	Expt.	Control	Errors	Expt.	Control
1–5	4	2	10–20	8	1
5–10	12	8	20–30	9	4
10–15	16	12	30–40	4	7
15–20	11	18	40–50	8	11
20–25	5	9	50–60	5	11
25–30	3	2	60–70	6	4
30–35	—	1	70–80	5	5
35–40	1	1	80–90	5	3
			90–100	—	5
			100–110	2	1
			110–120	—	—
			120–130	—	1

The distribution of error scores for the experimental group departs from the normal form so markedly that the sigma value computed has little meaning. The difference, 9.84 bears to its standard error a ratio of 1.99, which, if the distributions were both normal would indicate that the chances of there being a true difference would be 97 in 100, but in this instance this critical ratio is probably too conservative as an index of reliability. Can it possibly be a matter of chance that so many cases in the experimental group fall within the first two class intervals on the error scale? The several extreme deviates in the downward direction in the experimental group make the standard deviation of the distribution of error scores large, and likewise the standard error of the mean and the standard error of the difference between this mean and the corresponding mean for the control group are augmented. But our ordinary methods

are based upon the assumption of normal distributions, and it would seem that our critical ratio of 1.99, while suggesting a fair degree of reliability, hardly does our data justice.

It will be observed (Table III) that there are no significant differences between mean scores for the two groups on the practice pattern which was learned by both groups under identical conditions, *i.e.*, without shocks for errors. There is a slight but very unreliable difference in favor of the shock group in point of trials, but the difference in errors is very small and in the reverse direction. As regards time, the small difference also favors the control group. Thus it would seem that the groups were fairly well equated with respect to the learning ability involved in the experiment.

TABLE III

GIVING MEANS, STANDARD DEVIATIONS, DIFFERENCES AND CRITICAL RATIOS FOR TRIALS, ERRORS AND TIME FOR THE PRELIMINARY PRACTICE PATTERN, LEARNED UNDER THE SAME CONDITIONS BY BOTH GROUPS

Criterion	Experimental		Control		Difference	$\frac{\text{Diff.}}{\sigma \text{ Diff.}}$
	Mean	σ	Mean	σ		
Trials	6.50	5.00	6.71	4.1	.21	.233
Errors	12.65	10.44	12.55	8.4	.10	.05
Time	75.51	—	73.56	—	1.95	—

The verbal reports of the subjects learning with non-informative shocks as penalties for errors would indicate that thirty-one of the fifty-three found the shock definitely annoying or disagreeable. Thirteen thought that they would have done better without the shock, fifteen thought they would not have done as well, while twenty-four indicated that in their opinion the shock made no difference. Only seven reported that they tried to avoid shocks by trying to make fewer errors.

DISCUSSION

In general the results of the present experiment lend further support to the conclusion drawn from our stylus maze data of earlier experiments, that electric shocks administered for errors made during learning may have upon learning a

facilitating effect even though they be introduced in such a way that they can have no signal or informative value. The experimental group is slightly superior to the control group according to all three criteria—trials, errors and time. The most significant difference is that between mean error scores, which is what we might expect since the shocks were given more directly as penalties for errors, and not as penalties for requiring a larger number of trials or a longer time for learning.

The differences between means for experimental and control groups are not as large in proportion to their standard errors as were the corresponding differences for stylus maze performance, even though the punchboard type of maze might be expected to yield less variable data. One reason for the smaller differences may be that the learning of the punchboard involves a greater amount of verbalization, or its equivalent in the way of implicit symbolic response. Undoubtedly the shock has in addition to its facilitating effect, a counter disruptive effect. It represents a distracting stimulus, and it upsets the subject's verbal formulations. While the learning of the stylus maze also involves the formation of implicit symbolic habits, verbal or otherwise, a certain amount of non-symbolic habit formation probably occurs also, and this is of a type that is not involved in the learning of the punchboard. Since the punchboard is more completely verbalized, the shocks have on the whole a greater inhibitory effect. However, in spite of any disruptive effects there may be, the net effect of the shocks for the experimental group as a whole seems to be in the direction of facilitation. It is probable that the differences would have been larger in proportion to their standard errors if the pattern employed had been more complex and more difficult to master.

The bimodal nature of the error distribution for the experimental group would suggest that there may be two types of subject—one for whom the shock is an incentive and not a distracting influence to any great extent, and another for whom the shock either has no effect, the facilitating and inhibiting effects being balanced, or for whom the shock is more inhibiting than it is facilitating.

It will be noted that the shock group is more variable in its performance according to all three measures—trials, errors and time. It must be admitted, however, that the shock group was also more variable in its performance on the preliminary board which was learned under the same conditions by both groups. Therefore the differences in variability may not be significant from the point of view of the effect of the shock. In other words, our two groups seem to be fairly well equated with respect to general level of performance as measured by mean score values, but they may not be so well equated with respect to variability of performance. (The results of our stylus maze experiment indicated that the control group was the more variable in its performance throughout.)

In explanation of the facilitating effect of the non-informative shock little can be attempted at this time in addition to the suggestions offered in our previous article, in which we proposed interpreting our human learning data in somewhat the manner that Muenzinger has interpreted his animal findings (7). He writes that ". . . the function of moderate electric shock . . . is general rather than specific—it affects the total performance rather than the part-response it accompanies. In other words, its function is to make the animal respond more readily to the significant cues in the learning situation rather than that of inhibiting or facilitating the response which was shocked." In our 'non-informative shock' experiments no particular responses were 'shocked'—and yet apparently there was a facilitating effect. Therefore the effect must have been general.

To supplement the above interpretation given in terms of making the organism respond more readily to significant cues in the learning situation, or making it more alert as it were, we have made use of Guthrie's explanation of emotional reenforcement of learning (6). If we may assume that the electric shocks arouse emotional reactions, this might apply. Guthrie, who would interpret all aspects of learning in terms of the conditioned response concept, maintains that no response is ever directly conditioned upon external stimuli. In order for an external stimulus to become a substitute

stimulus for a given response, it must arouse some motor response on its own account prior to the conditioning in question. The response which is apparently directly conditioned upon the external stimulus is really most directly associated with the proprioceptive stimuli furnished by the motor reactions which the external stimulus calls out 'on its own account.' Thus proprioceptive 'conditioners' are important—yes, necessary—in any process of learning. In emotional excitement we have more vigorous response, and perhaps more complete reactions or larger patterns of response, and therefore more proprioceptive stimuli are provided. "These added stimuli may become conditioners of movement and hence explain the increased certainty of conditioning."

We have remarked heretofore that there are indications that electric shocks given for errors in learning may have different effects when administered in different ways and under different conditions (**4**). While shocks may under certain conditions have a facilitating effect upon learning, they undoubtedly act more or less as distracting stimuli at the same time. Also it would seem possible to have emotional inhibition as well as emotional facilitation. The net effect of the shock depends upon many factors, among them the intensity of the shock stimulus, the frequency of occurrence of the shocks, and the stage of learning at which they are introduced. In this connection we have reported that the learning of a stylus maze was no better with a shock for each complete entrance into a blind alley than it was when an auditory signal was given for each error of this type (**3**); yet our group learning the same maze with non-informative shock did significantly better than a control group (**4**). At first glance it might seem that we have here conflicting evidence, but we have suggested that the apparent discrepancy may be explained in terms of the difference in frequency of occurrence of shocks and the time at which the first shocks were introduced. It is possible that the shock-for-each-error group failed to do better than the auditory signal group because the subjects of the former group began receiving shocks very early in the game, before they had been able to become fairly

oriented in the rather novel situation—and that any facilitating effect that the shocks might have had over and above their signal function in later stages of learning would be offset by the distracting effect or disruptive emotional effect which they would have during the earlier stages. On the other hand the subjects of the non-informative shock group did not receive their first shocks until several errors had been made, and the shocks were for them less numerous and less frequent.

Since the acceptance for publication of the article containing the interpretations outlined above, Bunch has published the results of an investigation of the facilitating effect of shocks for errors as a function of the stage of learning at which the shocks are introduced (1). Her findings lend support to our assumption that the effect of shocks depends upon the way in which they are administered, particularly as regards the time of introduction. Bunch finds that when shocks are introduced during only a limited number of trials, *e.g.*, 2 or 4, the effect upon learning is a function of the stage of learning at which such shocks are introduced. The facilitating effect is greater when they are introduced at the third trial than when they are administered earlier in learning, and their effect is greater than when there are more trials with shocks earlier in learning, and slightly greater than when shocks are given for errors during all trials. The explanation of these differences given by Bunch is similar to that we have suggested above to explain our apparently conflicting data.

Summary

The aim of the experiment was to obtain additional data with respect to the effect upon learning of electric shocks, given as penalties for errors in such a manner as to eliminate the guidance factor. The subjects were 105 college students, distributed in a control group of 53 and an experimental group of 52. The subjects of both groups learned two modified punchboard maze patterns. The first was a preliminary practice pattern, which was learned by both groups under the same conditions. The second was learned by the control group with clicks to indicate correct choices; by the

experimental group it was learned with the same clicks for correct responses and in addition electric shocks were given at the rate of one for every five errors during the early stages of learning, and one for every two or three errors thereafter. No shocks accompanied or immediately followed the commission of an error. The mean number of trials, errors and seconds of learning time were compared for the two groups.

The experimental group was found to be superior to the control group according to all three criteria. The differences in trial and error scores are fairly but not highly reliable, but the error difference may be more reliable than the critical ratio would indicate, since the error distribution for the experimental group departs markedly from the normal form. The difference in time scores is not reliable.

It may be concluded that the findings of the present experiment together with Bunch's experimental results lend further support to our earlier statement based upon stylus maze data—namely, that electric shocks given for errors made during learning have, at least under certain conditions, a facilitating effect upon learning apart from their effects as signals or guiding cues.

(Manuscript received July 17, 1936)

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